GRAND RIVER BASIN WATER MANAGEMENT STUDY

TECHNICAL REPORT SERIES

REPORT # 27

RURAL NON-POINT SOURCE POLLUTION AND CONTROL

Prepared for the Grand River Implementation Committee

by

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March, 1982

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FOREWORD

The report "Rural Non-Point Source Pollution and Control" is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and, in itself, does not necessarily constitute policy or management priorities. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this one report but should be analyzed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Study, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

CREDITS AND ACKNOWLEDGEMENTS

The authors wish to express their deep appreciation to all the members of the Ad Hoc Diffuse Source Committee: J. Arnold, Dr. T. Dickinson, J. Johnston, P. Mason and A.F. Smith for their guidance, advice and support throughout this study. Their constructive suggestions and criticisms in the preparation of this report are gratefully acknowledged.

Thanks are due to Dr. M.H. Miller, the University of Guelph; J. Haggarty, D. Graham and D. Keyes, the Ministry of Agriculture and Food; for sharing with us their views on the trends of agricultural land use in the Grand River basin.

The authors wish to thank Dr. R. Frank, the Ministry of Agriculture and Food, who presented an overview on the usage of important pesticides in Ontario, their persistence and impact on the environment; Dr. G. J. Wall, the Ontario Institue of Pedology, Agriculture Canada, who presented an overview on the role of sediment from rural non-point sources in Great Lakes pollution; J. Arnold, the Ministry of Agricuflture and food, who provided a glossary of agricultural terms for this report; and T. J. Vyn who provided input in the description of conservation tillage.

The authors wish to acknowledge the efforts of G. Neilson and H. MacDonald who conducted the field surveys described in this report; P. Frigon, the Grand River Conservation Authority, who compiled agricultural census data for the basin; D. Veal, the Grand River Conservation Authority, who compiled data on soil texture and livestock operations for the study; M. Wharram, S.M. Schneider and L.E. Oakley, Water Resources Branch, who assisted in the preparation of this report. Comments on the report by J. Rahston, Water Resources Branch, are appreciated.

Finally, the authors wish to acknowledge the assistance provided by staff members of the Word Processing Unit.

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1. INTRODUCTION

Water quality at many locations along the Grand River and its tributaries was often in non-compliance with the Provincial water quality objectives for the protection of aquatic life and recreation (GRBWMS, 1979). Pollution problems associated with suspended solids, phosphorus and nitrogen were among those of major concern. By relating pollutant loadings to land use, the PLUARG Grand River pilot watershed study determined that a large portion of the loadings - 84% of the sediment, 67% of the total phosphorus, 56% of filtered reactive phosphorus, 47% of the total Kjeldahl nitrogen and 81% of nitrite and nitrate - came from rural diffuse sources (Hore and Ostry, 1978).

At present, water quality in the northern part of the basin, where agriculture is predominant, is affected primarily by erosion. Soils and nutrients are carried into the river causing turbidity, nutrient enrichment and limited, localized algal growth. During 1975 and 1976, this part of the basin contributed to the Grand River about 4200 tonnes of suspended solids (51.3 kg/ha/year), 17 tonnes of total phosphorus (0.2 kg/ha/year) and 229 tonnes of total Kjeldahl nitrogen (2.7 kg/ha/year). At the first concession downstream of Belwood Lake, the annual mean concentrations of suspended solids, total phosphorus and total Kjeldahl nitrogen were 18 mg/L, 0.06 mg/L and 0.75 mg/L, respectively. With the exception of localized aquatic growth, water quality problems in this part of the basin are limited in extent and do not have significant detrimental impact on river uses.

The heavily urbanized and industrialized central part of the basin is significantly affected by the discharge of treated domestic and industrial wastes, urban stormwater runoff as well as agricultural runoff. Two of the major problems that have been identified through the Grand River Study are: 1) the reduction of dissolved oxygen in areas downstream from the major municipalities caused by municipal discharges of oxygen-consuming wastes; and 2) profuse algae and plant growth stimulated by nutrient inputs from point and nonpoint sources.

The western part of the basin includes the Conestogo River, the Nith River, Canagagigue Creek and Irvine Creek watersheds. At present, these watersheds are used extensively for agricultural production and contribute significant amounts of pollutants to receiving waters. For example, during 1975 and 1976, the pollutant loads measured at the mouth of the Nith River averaged 70208 tonnes of suspended solids (688 kg/ha/year), 124 tonnes of total phosphorus (1.2 kg/ha/year) and 532 tonnes of total Kjeldahl nitrogen (5.2 kg/ha/year). These loads are much higher than those measured at the northern part of the Grand River basin reflecting more intensive agricultural activities in the Nith River basin.

The lands of the lower part of the basin are primarily used for agriculture and the problems encountered there are quite similar to those identified earlier for the northern part of the watershed (Jeffs et al, 1978).

In light of the water quality problems identified in the Grand River (including severe dissolved oxygen deficits, an overabundance of aquatic plants and high concentrations of phosphorus and suspended solids in certain reaches), there appears to be a real need to reduce the loadings of sediment, phosphorus and nitrogen from all sources.

Water quality constitutes an important component of the Grand River Basin Water Management Study. The key elements of water quality investigation are:

1. to determine existing water quality conditions and relate them to various water uses;

2. to identify the type, magnitude, relative significance and impact of pollutants from point and nonpoint (urban and rural) sources on the water quality of the river; and

3. to develop water quality management programs to preserve areas of high water quality and to upgrade areas where poorer water quality exists.

Agricultural runoff has been recognized as a potential major contributor of polluting materials to the Grand River. Therefore, investigation of pollution from rural sources became an integral part of the basin's water quality assessment program.

The objectives of this study are:

1. to investigate how natural land forms, agricultural land use, and agricultural land management practices affect the loadings of suspended solids, total phosphorus, filtered reactive phosphorus, total Kjeldahl nitrogen and filtered nitrite and nitrate to the Grand River;

2. to project rural non-point source pollutant loads to the years 2001 and 2031 under various land use scenarios;

3. to identify remedial measures that can be used to reduce rural non-point source pollutant loads; and

4. to evaluate the costs and effectiveness of the remedial measures identified.

This report is divided into eight sections. A general description of the Grand River basin is presented in Section 2. In Section 3, major agricultural pollutants, the temporal variation in pollutant transport, and the concept of hydrologically active areas are described. Pollutant load estimates obtained for the rural non-point sources in the Grand River basin are presented and compared with the urban sources. In Section 4, four major factors that affect rural non-point source pollution are described. Data derived from field surveys and aerial photographs interpretation are presented in Section 5. The causes of pollutant contributions, with respect to natural land forms, agricultural land use and management practices are discussed in Section 6. Five regression models, developed to relate unit-area pollutant loads to agricultural land use are presented in Section 7 together with pollutant loads projected to the years 2001 and 2031. Remedial measures, their costs and effectiveness are discussed in Section 8.

2. DESCRIPTION OF THE GRAND RIVER BASIN

2.1 LOCATION

The Grand River basin is located in southwestern Ontario between longitudes 79° 30' and 80° 57' W, and latitudes 42° 51' and 44° 13'N. The basin occupies the central part of a peninsula bounded on the north by Georgian Bay, on the west by Lake Huron, on the south by Lake Erie and on the east by the western end of Lake Ontario (Figure 1). The basin has an area of 6965 km^2, a length of about 300 km and a width which varies between 5 and 75 km.

The Grand River basin comprises practically the whole of the Counties of Brant, Waterloo and Wellington, and parts of Dufferin, Gray, Haldimand, Halton, Norfolk, Oxford, Perth and Wentworth.

2.2 PHYSIOGRAPHY

The physiography of the Grand River basin is a direct result of deposition and erosion during glacial and post-glacial times. During the Pleistocene age, the Grand River basin was subjected to glaciation from several directions. From the north came the ice of the Georgian Bay ice lobe, from the southeast and east came the ice of the Erie-Ontario ice lobe, and from the west and northwest came the Huron ice lobe. These lobes met and oscillated several times in the central part of the Grand River basin, forming interlobate moraine deposits, drumlin fields, till plains and end moraines. During deglaciation large quantities of meltwater reworked the till and laid it down elsewhere in stratified and sorted beds of gravel, sand, silt and clay. Deposits in stream beds confined in subglacial tunnels were left as eskers; other steep-sided masses formed against the ice edge became kames and accumulations in glacial lakes formed silt and clay plains.

As the glacial lakes receded to the present stages of the Great Lakes, drainage patterns developed and land forms were further sculptured by erosional processes.

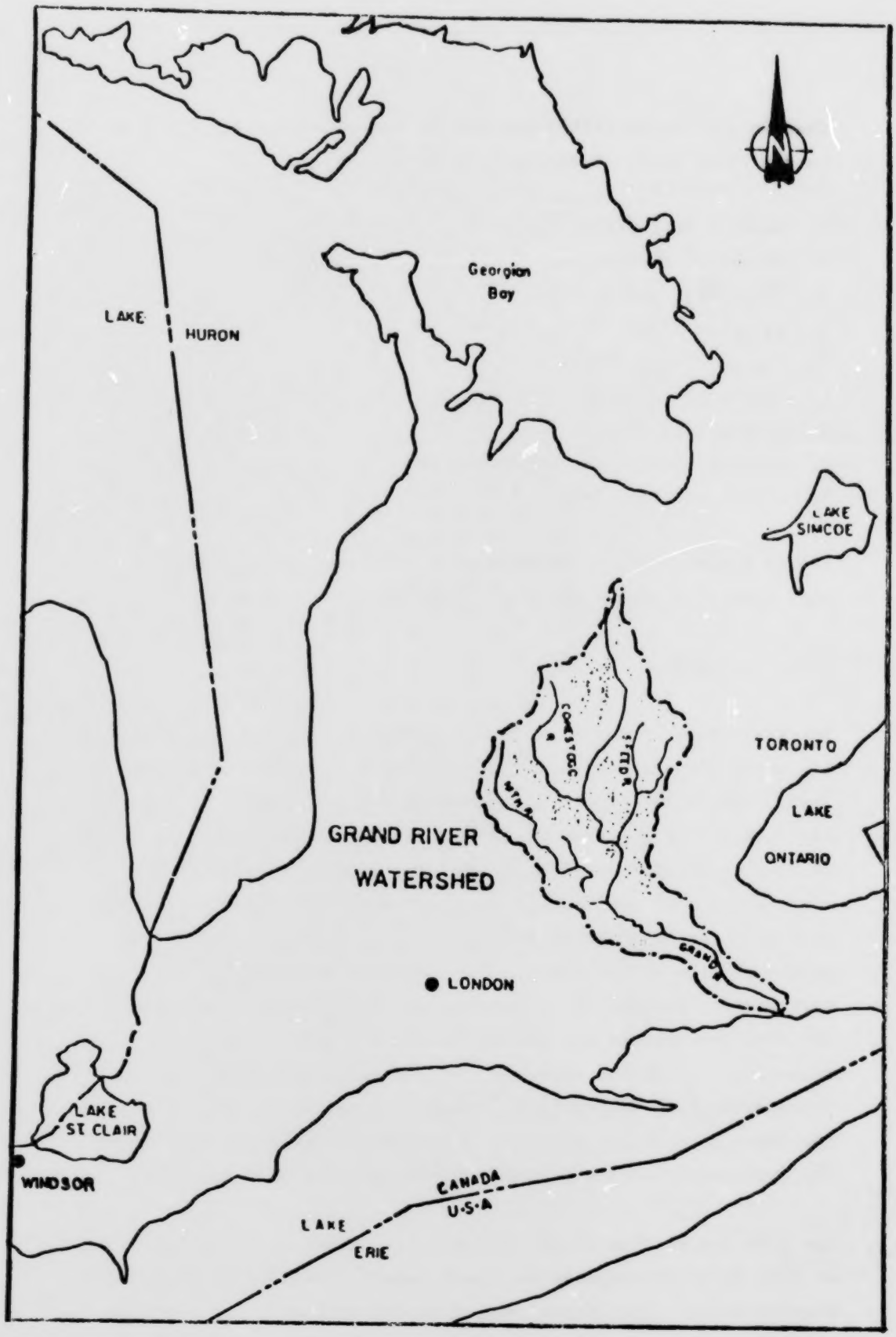


Figure 1. Location of the Grand River Basin in Southwestern Ontario.

Chapman and Putnam (1951) identified nine major physiographic units in the study area. These units are:

1. Dundalk till plain,
2. Stratford till plain,
3. Hillsburgh sand hills,
4. Waterloo hills,
5. Guelph drumlin field,
6. Horseshoe moraines,
7. Flamborough plain,
8. Norfolk sand plain, and
9. Haldimand clay plain.

Figure 2 shows the approximate areal distribution of these physiograpic units in the Grand River basin.

2.3 DRAINAGE

The Grand River rises in a massive swampy upland south of Georgian Bay at an elevation of approximately 525 m above mean sea level (msl). The river flows in a southerly direction until it reaches the Town of Paris. From there it follows a southeasterly direction to discharge into Lake Erie at Port Maitland at an elevation of 174 m above mean sea level. The Conestogo, Speed and Nith rivers are the three major tributaries which join the main stem in the middle portion of the basin. The Conestogo River drains the northwestern portion of the basin with the Speed and Nith rivers draining the eastern and western portions of the basin, respectively. In the upper part of the basin, the Grand and its tributaries flow in previously formed glacial spillway channels. In the lower part, below the City of Brantford, the river has scoured its own channel across glacial lake deposits of silt and clay.

The mean annual flow at the outlet of the river is estimated to be 64 m^3/s which corresponds to a mean annual runoff of 30 cm of precipitation. Peak flows range from 500 to 1400 m^3/s, and they usually occur during the spring melt period. The highest flow on

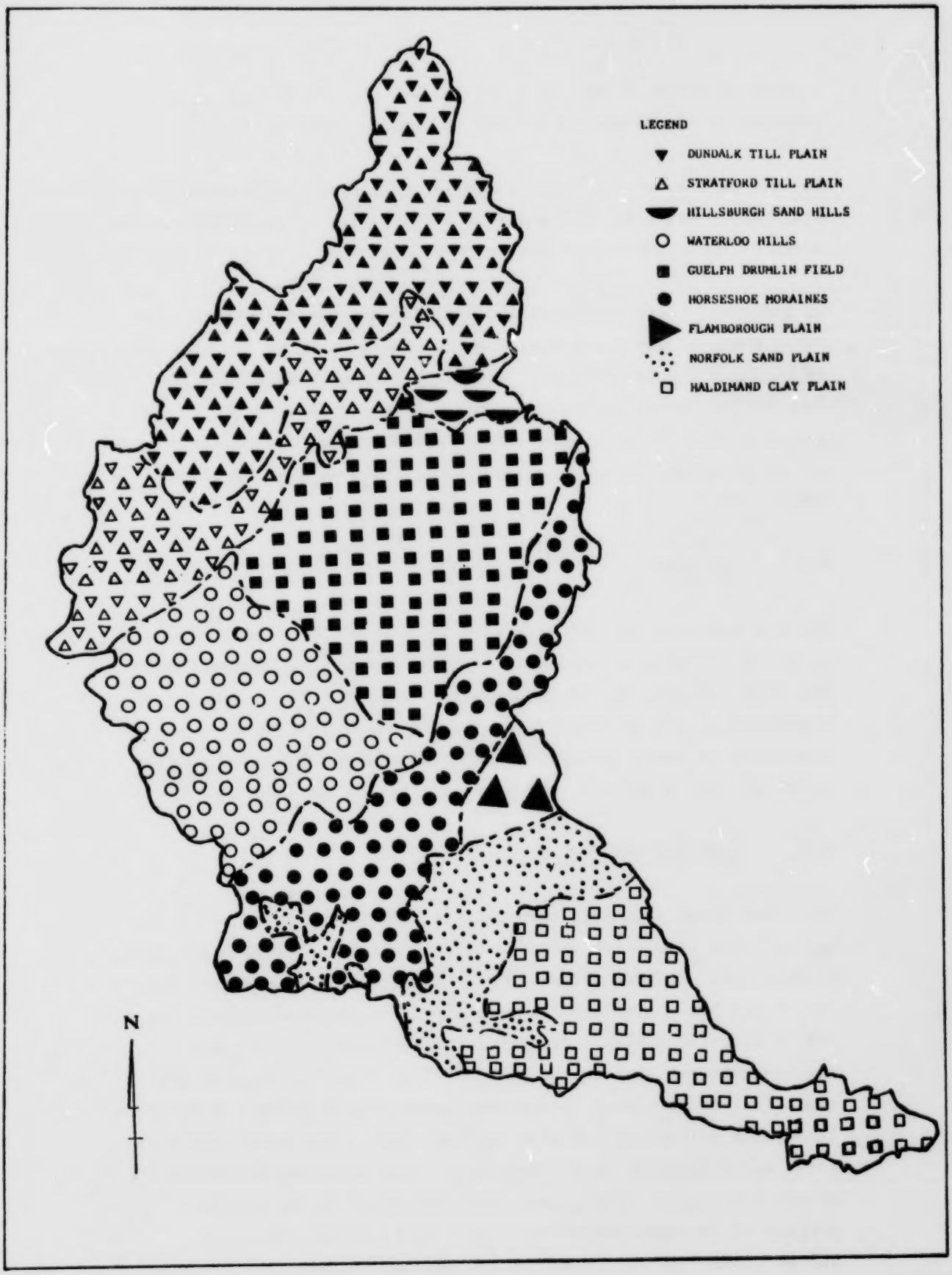


Figure 2. Physiographic Units in the Grand River Basin.

record, occurred in May, 1974 when a flow of 1784 m^3/s was recorded at the Brantford streamflow gauging station.

For the purpose of the rural non-point source pollution study, the Grand River basin was divided into 8 sub-basins. The boundaries and areas of these sub-basins are shown in Figure 3.

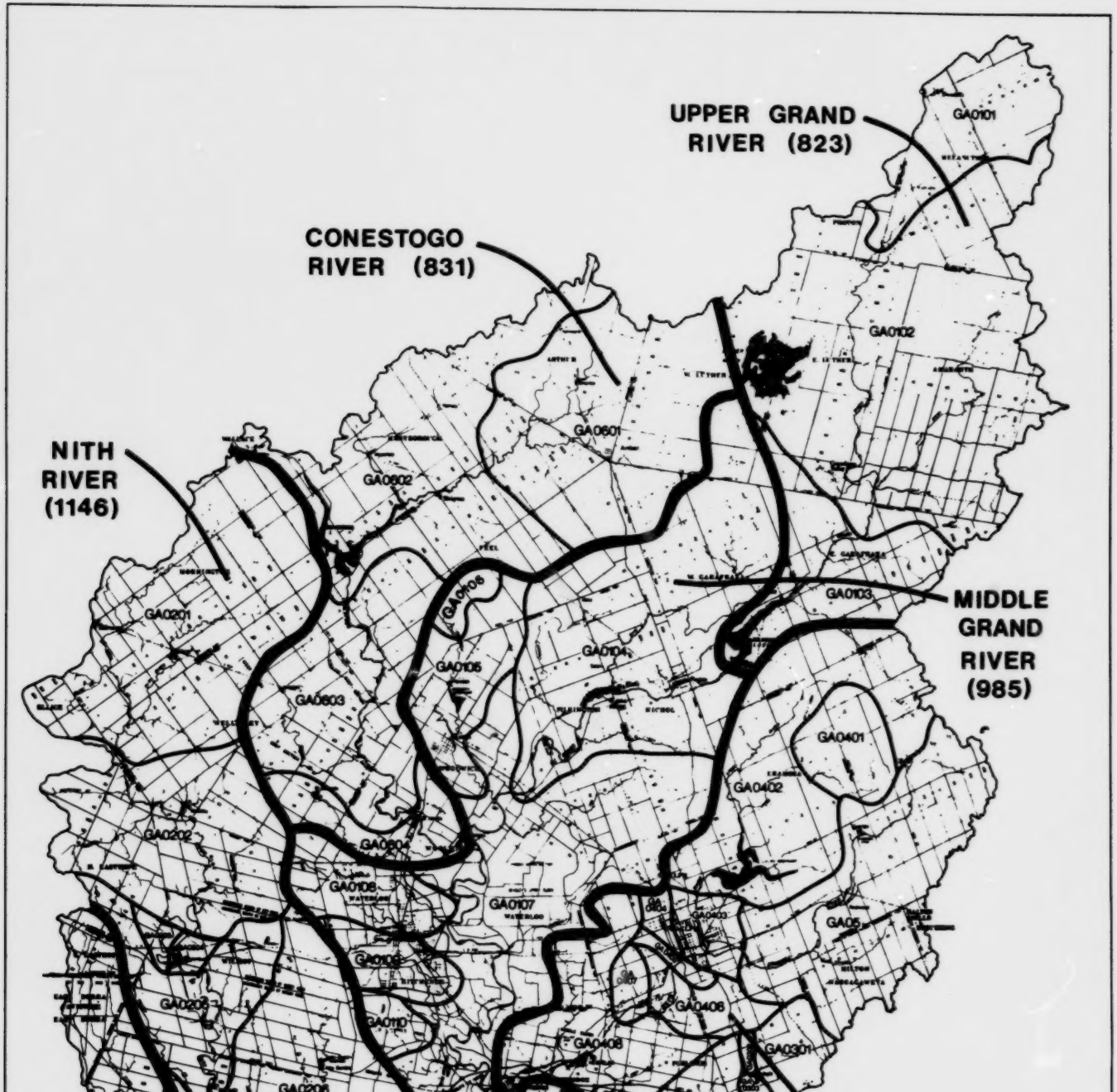
In addition, there are extensive man-made drainge networks in the rural areas of the Grand River basin. These drainage networks serve to increase the agricultural capability of poorly drained soils through the removal of excess water. Between 1965 and 1976, approximately 658 km of open drains and 301 km of closed drains were installed in the basin. Together, they drain an area of 1464 km^2 (GRCA, 1979).

2.4 CLIMATE

The drainage basin is characterized by a temperate climate that receives a moderating influence from the nearby Great Lakes System. The long-term mean annual temperatures vary from 6°C in the headwaters to 9°C at Lake Erie. The long-term mean annual precipitation varies from 84 cm (178 cm snow) in the lower reaches to 88 cm (127 cm snow) in the upper reaches of the basin.

2.5 LAND USE AND POPULATION

The Grand River basin has been developed extensively for urban and agricultural uses which comprise 3% and 77% of the total basin area, respectively. Wooded and/or idle areas account for approximately 19% of the basin area and the remaining 1% lies in other uses (extractive industries, transportation corridors, etc.). Most of the agricultural area in the basin (72% of total basin area) was classified as farm land in the 1976 agricultural census. Under farm lands, the following land uses are included: crop land, pasture, ponds and unimproved land. Crop land constitutes approximately 51% of the basin area. Urban uses are predominant in the central portion of the basin where the cities of Kitchener, Waterloo, Guelph, Cambridge and Brantford are located (Figure 4).


UPPER GRAND RIVER (823)
CONESTOGO RIVER (831)
NITH RIVER (1146)
MIDDLE GRAND RIVER (985)
GA0101
GA0102
GA0103
GA0104
GA0105
GA0106
GA0107
GA0108
GA0109
GA0110
GA0201
GA0202
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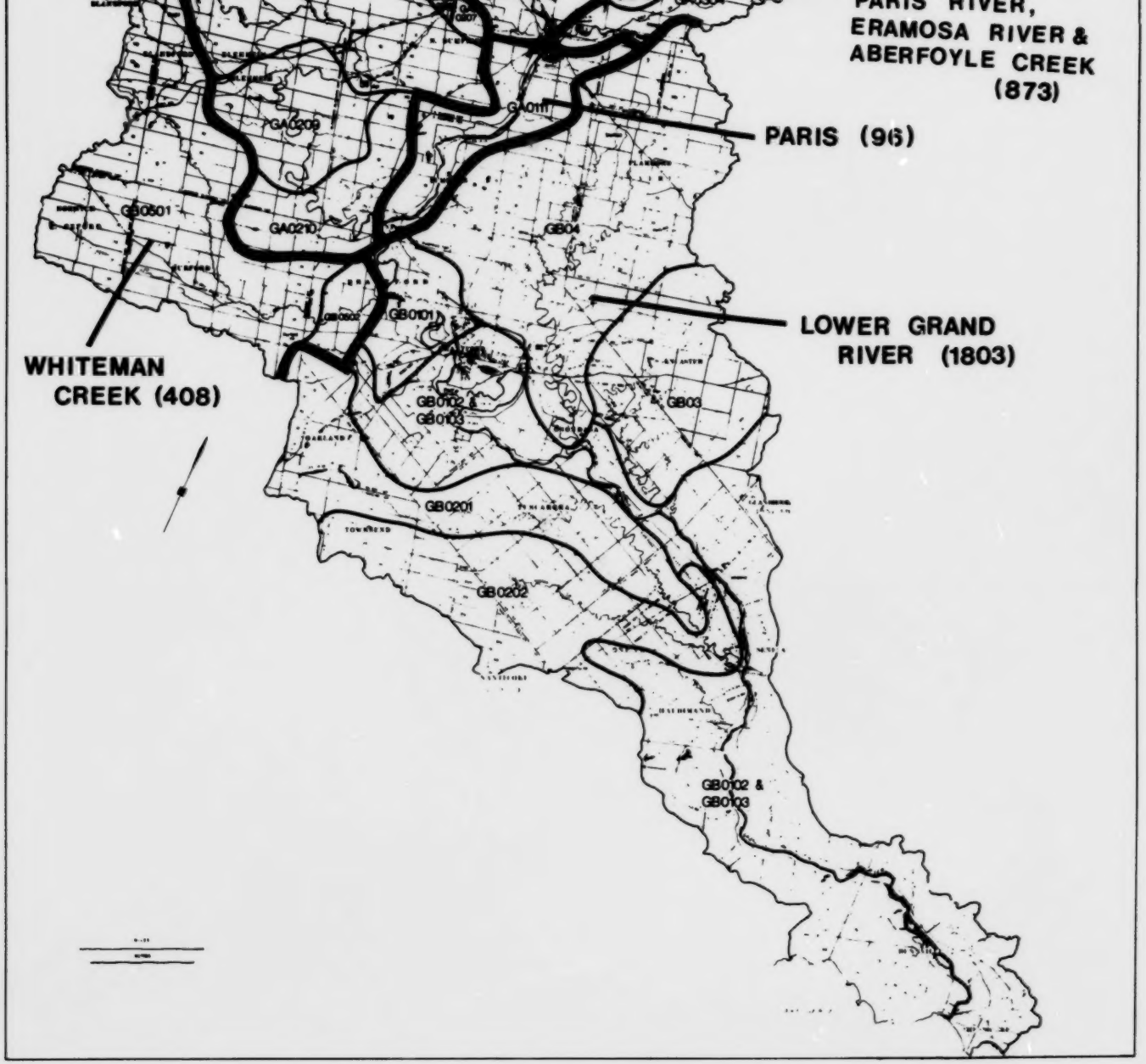

Figure 3. Sub-Basin Divisions in the Grand River Basin (Area in km^2)

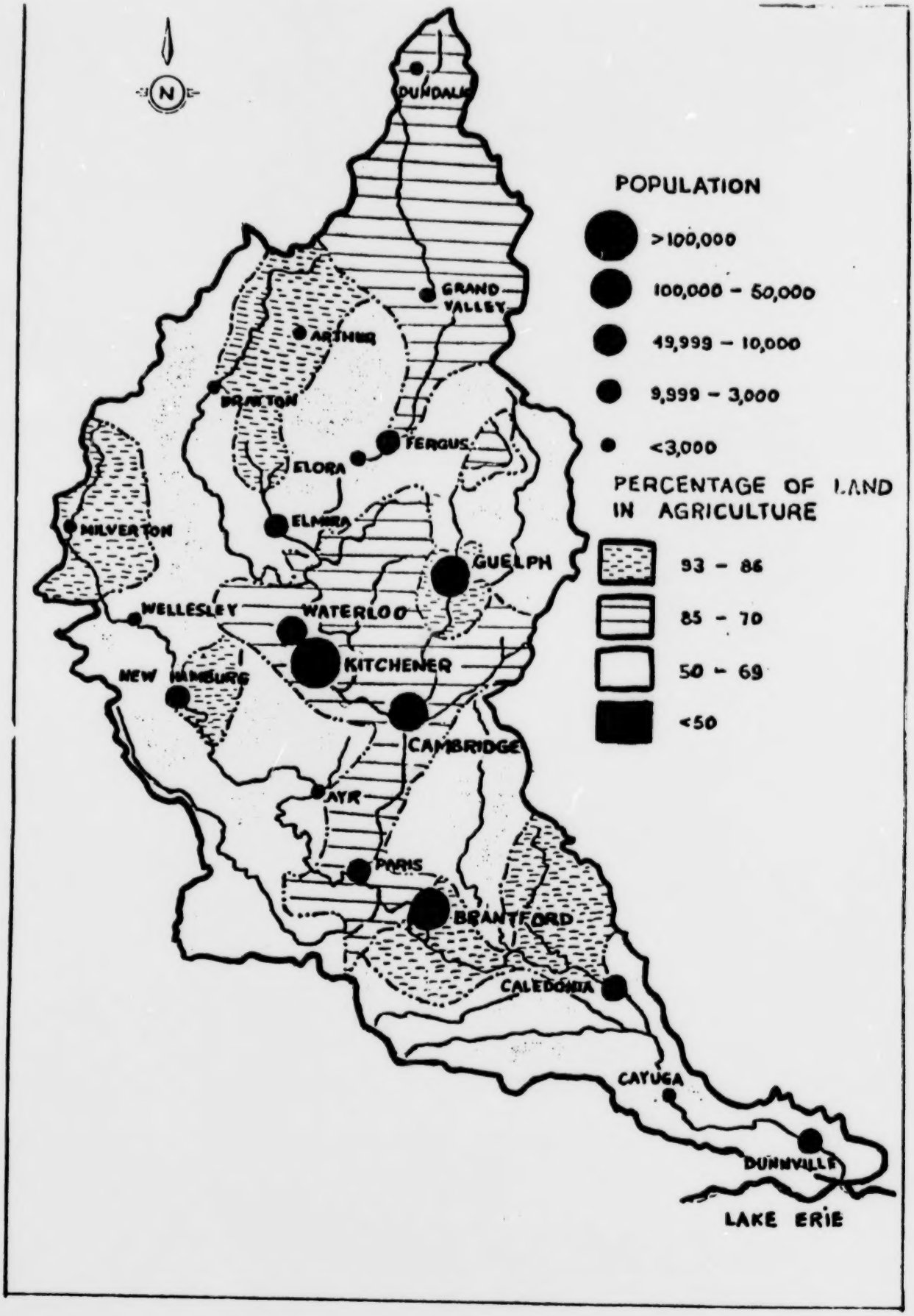

Figure 4. Population and Land Use Distribution in the Grand River Basin.

The population of the basin is approximately 573,000 and is primarily concentrated in the above mentioned five large urban centres. This, however, has not always been the case. In 1921, 43% of the basin's population was rural and only 47.5% lived in the five urban centres. By 1976, however, the proportion of rural population dropped to about 20% whereas the proportion of population in the five urban centres increased to 72%. If these trends continue through subsequent years, it can be expected that by the year 2001 the urban population might increase by about 200,000 to 300,000 people.

2.6 SOILS

During the PLUARG study (Sonzogni et al, 1980), it was found that among all land form charateristics, the single most important factor related to non-point source pollution problems is soil texture. The soils of the Grand River basin have developed in parent materials ranging in texture from coarse gravels to clays. These soils are the product of the environmental conditions under which they developed including factors such as climate, vegetation and drainage. Figure 5 shows the areal distribution of various deposits which constitute the parent materials on which the soils of the Grand River basin have developed.

Most of the major types of soils in the basin have a fully developed soil profile in which the A, B and C horizons are recognizable. The remaining soils, mainly those which occur in poorly drained areas, show evidence of imperfect development. Table 1 gives the areal distribution of various soils in the Grand River basin based on their drainage characteristics.

A fairly high content of calcareous matter is present in most soils of the Grand River basin, however, deficiency in organic matter and phosphate is a common drawback to the natural fertility of these soils. A brief description of the major soils in the Grand River basin and their capability for agriculture are given in Appendices 1 and 2, respectively.

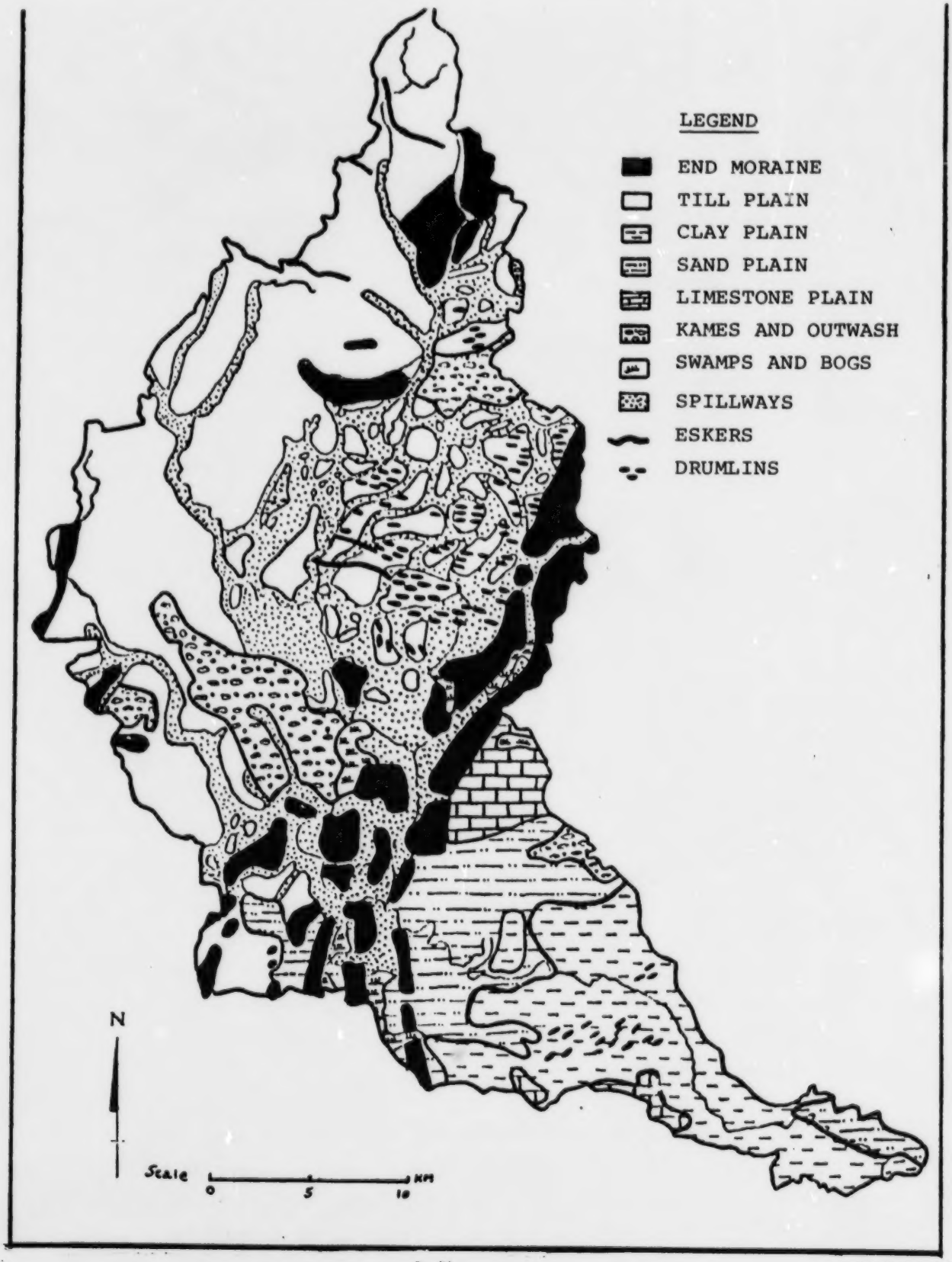

Figure 5. Soil Parent Materials in the Grand River Basin.

Table 1. Areal Distribution of Soils in the Grand River Basin Based on their Drainage Characteristics

Sub-Basin	Area ha	Well Drained %	Imperfectly Drained %	Poorly Drained %
UPPER GRAND RIVER				
GA0101	12513	15	27	58
GA0102	56385	15	20	65
GA0103	13400	74	13	13
CONESTOGO RIVER				
GA0601	27707	23	62	15
GA0602	28829	46	42	12
GA0603	21000	59	14	27
GA0604	5562	60	33	7
MIDDLE GRAND RIVER				
GA0104	36752	57	33	10
GA0107	38276	64	31	5
GA0108	6554	90	2	8
GA0109	3952	97	0	3
GA0110	2191	98	0	2
CANAGAGIGUE CREEK				
GA0105 + GA0106	10761	51	41	8
SPEED RIVER				
GA0401	5705	70	11	19
GA0402	22148	76	10	14
GA0403	2235	89	4	7
GA0404	1022	64	22	14
GA0405	650	85	2	13
GA0406	4169	84	4	12
GA0407	1219	87	10	3
GA0408	13682	84	5	11
ERAMOSA RIVER				
GA05	26505	70	7	23
ABERFOYLE CREEK				
GA0301	3153	73	2	25
GA0302	249	80	9	11
GA0303	416	92	0	8
GA0304	6108	82	8	10

Table 1 (Cont'd)

Sub-Basin	Area ha	Well Drained %	Imperfectly Drained %	Poorly Drained %
GRAND RIVER AT PARIS				
GA0111	9617	85	10	5
NITH RIVER				
GA0201	32363	19	56	25
GA0202	21900	74	4	22
GA0203	902	81	1	18
GA0204	741	97	3	0
GA0205	11319	82	11	7
GA0206	26732	85	3	12
GA0207	821	91	0	9
GA0208	321	86	0	14
GA0209	9586	70	18	12
GA0210	9932	76	12	12
WHITEMAN CREEK				
GB0501	38115	64	25	11
GB0502	2639	66	24	10
BIG CREEK				
GB03	17262	84	12	4
FAIRCHILD CREEK				
GB04	40186	85	8	7
McKENZIE CREEK				
GB0201	20297	67	24	9
BOSTON CREEK				
GB0202	23083	85	15	0
LOWER GRAND RIVER				
GB0101	7271	75	15	10
GB0102	46399	93	6	1
GB0103	25207	-	-	-

2.7 CROPPING ACTIVITIES

Based on agricultural census data collected in 1976, there were approximately 3177 km^2 of crop land* in the Grand River basin (Figure 6). The three major crops were row crops** (35.5%), small grains*** (34.5%) and hay**** (30.0%).

Approximately 94.0% of the row crops grown in the Grand River basin in 1976 were corn. The remaining 6.0% were tobacco, vegetables, potatoes and and soybeans. Most of the small grains were mixed grains (58.0%). Other grains included wheat (14.0%), oats (13.5%), barley (13.0%) and rye (1.5%). Approximately 63.0% of the hay in the basin was alfalfa and the rest was tame hay.

The changes of agricultural land use within the Grand River basin during the first half of the 1970's were investigated through a comparison of the agricultural census data collected in 1971 and 1976 (Appendices 3 and 4). The most significant change was the conversion from small grains and hay to corn. The area of land used for corn increased from 865 km^2 in 1971 to 1055 km^2 in 1976 (a net increase of 190 km^2). On the other hand, small grains and hay decreased from 2235 km^2 to 2032 km^2 (a net decrease of 203 km^2). The small discrepancy between the net increase and decrease (13 km^2) is due to missing data and probably differences in sampling procedures used in the two agricultural census in 1971 and 1976. Figures 7 and 8 show the areal distribution of row crops in the Grand River basin in 1971 and 1976, respectively.

2.8 LIVESTOCK OPERATIONS

The four major types of livestock operations in the Grand River basin are cattle, swine, sheep and poultry. The distributions of each type of livestock in the basin in 1971 and 1976 are given in Appendices 3 and 4.

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* Cropland is defined as land used for the production of annual crops, and for orchards and vineyards. It includes row crops, small grains and hay.

** Row crops include corn, tobacco, vegetables, soybeans and potatoes.

*** Small grains include wheat, oats, barley, mixed grain and rye.

**** Hay includes alfalfa and other tame hay.

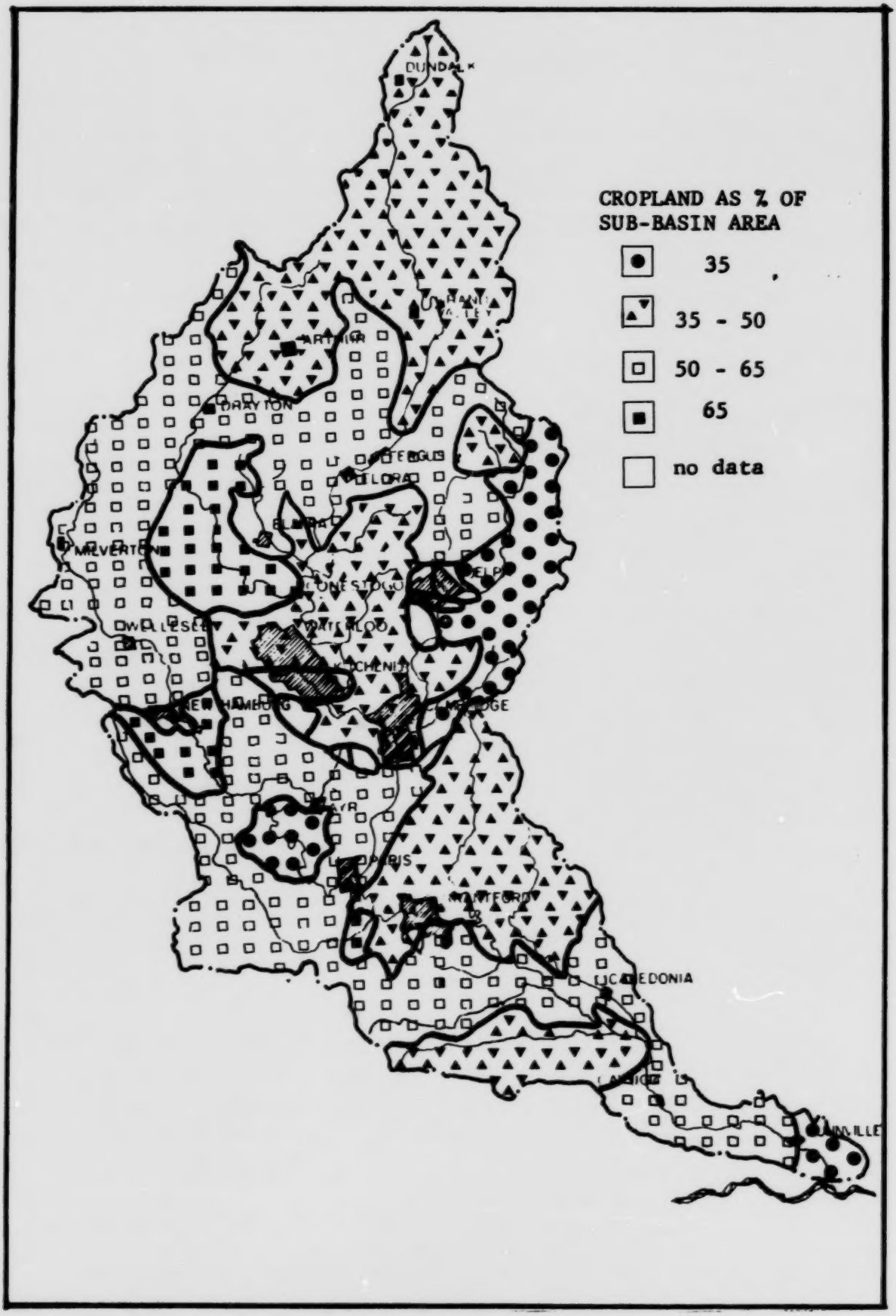


Figure 6. Distribution of Cropland in the Grand River Basin in 1976.

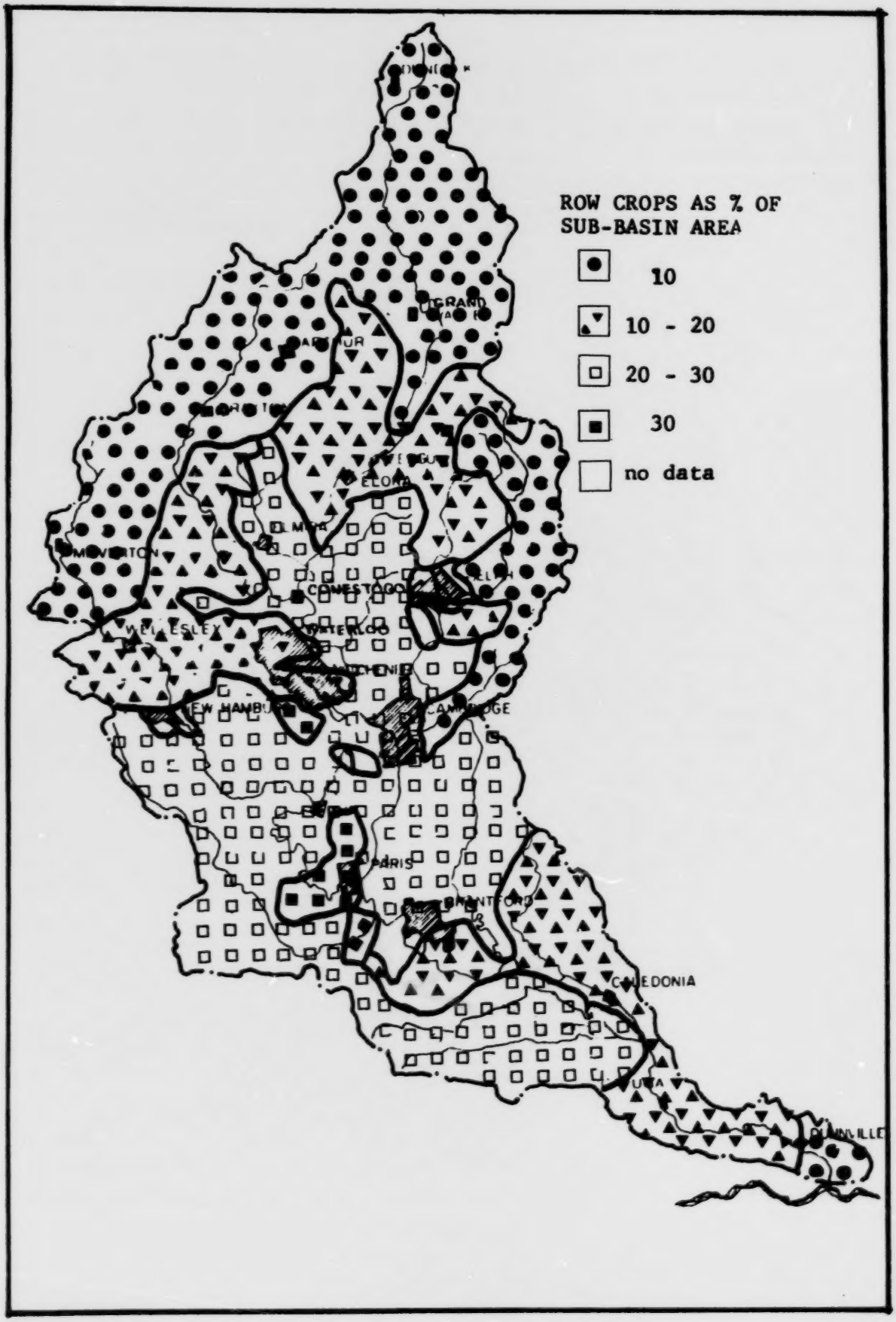


Figure 7. Distribution of Row Crops in the Grand River Basin in 1971.

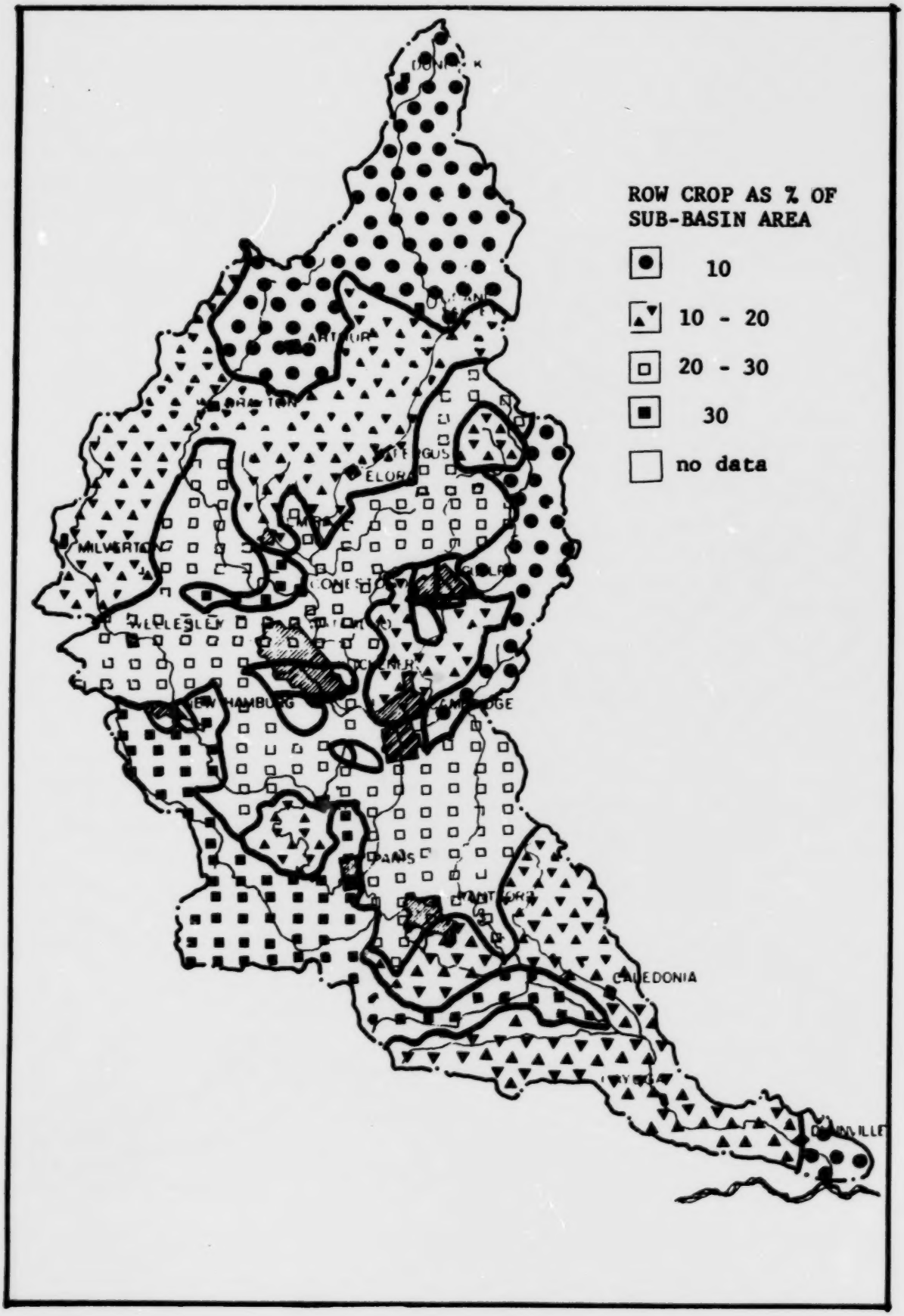


Figure 8. Distribution of Row Crops in the Grand River Basin in 1976

A comparison of the 1971 and 1976 livestock data shows that the number of pigs decreased by 16%; the number of sheep decreased by 41% while the number of chickens and cattle remained at the same level.

2.9 OTHERS

In 1976, there were about 43,000 private waste disposal systems (mainly septic tanks) in the Grand River basin (Chan, 1978). Approximately 83.0% of these systems were used by the rural population on a year-round basis. The rest were used mainly in the summer time by cottage residents.

3 POLLUTANT LOADS

3.1 MAJOR AGRICULTURAL POLLUTANTS

Agricultural water pollution is the degradation of water quality of receiving waters as a result of agricultural activities. The quality of agricultural runoff reflects the type of soluble material the water comes in contact with and the suspended material it carries. Major pollutants from agricultural lands usually include sediment, nutrients, pesticides, organic matter and micro-organisms.

3.1.1 Sediment

Soil particles detached by soil erosion which find their way into receiving waters become sediment. Sediment may be defined as a pollutant when it renders water unfit for a particular use either by its presence in suspension or as deposit on the bottom. The detrimental effects of sediment include obstruction of drainage channels, filling of reservoirs and deterioration of aquatic habitat. Sediment can also result in the clogging of gills of fishes and may interfere with spawning or breeding.

A major significance of sediment as a pollutant is related to its ability to serve as a vehicle to carry other pollutants such as nutrients, pesticides, trace organics and heavy metals into receiving waters.

3.1.2 Nutrients

Major nutrients, phosphorus and nitrogen, are introduced on farm land from animal wastes and through the application of fertilizers. Nitrogen generally finds its way into ground water and surface water in dissolved form and may accumulate and contribute to problems of toxicity. On the other hand, phosphorus occurs mainly in surface runoff because it tends to attach to soil particles. High levels of phosphorus induce nuisance growth of algae and other aquatic

plants. When present in abundance, aquatic plants interfere with the recreational use of a water body for such activities as swimming, fishing and boating. Through respiration, these plants deplete the oxygen levels in the water and render it unsuitable as a habitat for fish and other desirable forms of aquatic life.

3.1.3 Pesticides

Four major categories of pesticides are important in agriculture: insecticide, fungicide, herbicide and rodenticide. High levels of pesticides present a short-term threat whereas low levels present a long-term hazard. The primary threat from pesticides results from their persistence in the aquatic environment and their ability to accumulate in fish and other organisms in the food chain.

The major route of pesticides to the waterways is via erosion. Because of the tight binding characteristics of many pesticide residues to soil particles, it is suggested that, in general, pollution of waters by pesticides occurs through the transport of soil particles to which the residues are attached. Suspended plant material or leaching of crop residues are also pesticide transport mechanisms, but less dominant than the movement via soil erosion and sediment transport.

Pesticides are applied in varying quantities to almost all types of land in the Grand River basin. The PLUARG study indicates that only a limited number of pesticides were detected in the Grand River basin. Levels were generally too low to calculate precise pesticide load estimates (Sonzogni et al, 1980).

3.1.4 Organic Matter and Pathogens

Organic matter and bacterial organisms originate mainly in animal wastes. Livestock operations on sloping land with good drainage or in the immediate vicinity of surface water represent a pollution hazard. The problem is aggravated by cattle access into streams and spring runoff from manure spread on frozen or snow-covered sloping land.

3.2 TEMPORAL VARIATION OF POLLUTANT LOADS

Variations of pollutant loads from agricultural areas are observed on a seasonal basis. A large portion of the annual load occurs during the snow melt periods as well as during intense rainstorms. Based on data collected from the Grand River basin during the PLUARG program (Hore and Ostry, 1978) it was found that the bulk of the river loads (up to 80%) are transported during the months of February, March, April and May. Figure 9 shows the monthly percent distribution of pollutant loads of suspended solids, total phosphorus and filtered reactive phosphorus for the years 1975 and 1976 in the Nith River. A similar temporal distribution was observed at other stations in the Grand River basin.

Two implications from this temporal distribution of pollutant transport are of importance:

1. The most critical period with respect to pollution generation in the basin is the period between snow melt and the time when the vegetative cover is established. Therefore soil protection is most important during this period.

2. Most of the pollutant load generated during this period will not be retained in the river system but will be carried to the Great Lakes system because of high spring flows.

3.3 HYDROLOGICALLY ACTIVE AREA

Because of the variability of land forms, climatic conditions, land use and agricultural practices within a given agricultural watershed, the intensity of the erosion process is different from one place to another. It has been recognized that certain areas within a watershed, which are usually in close proximity to natural or man-made drainage ways, contribute more sediment loads than the remaining areas. These contributing areas are known as "hydrologically active areas". Recent studies (Wall et al, 1978) confirmed that approximately 10% to 20% of an agricultural watershed contributes the majority of the sediment load to the stream channels.

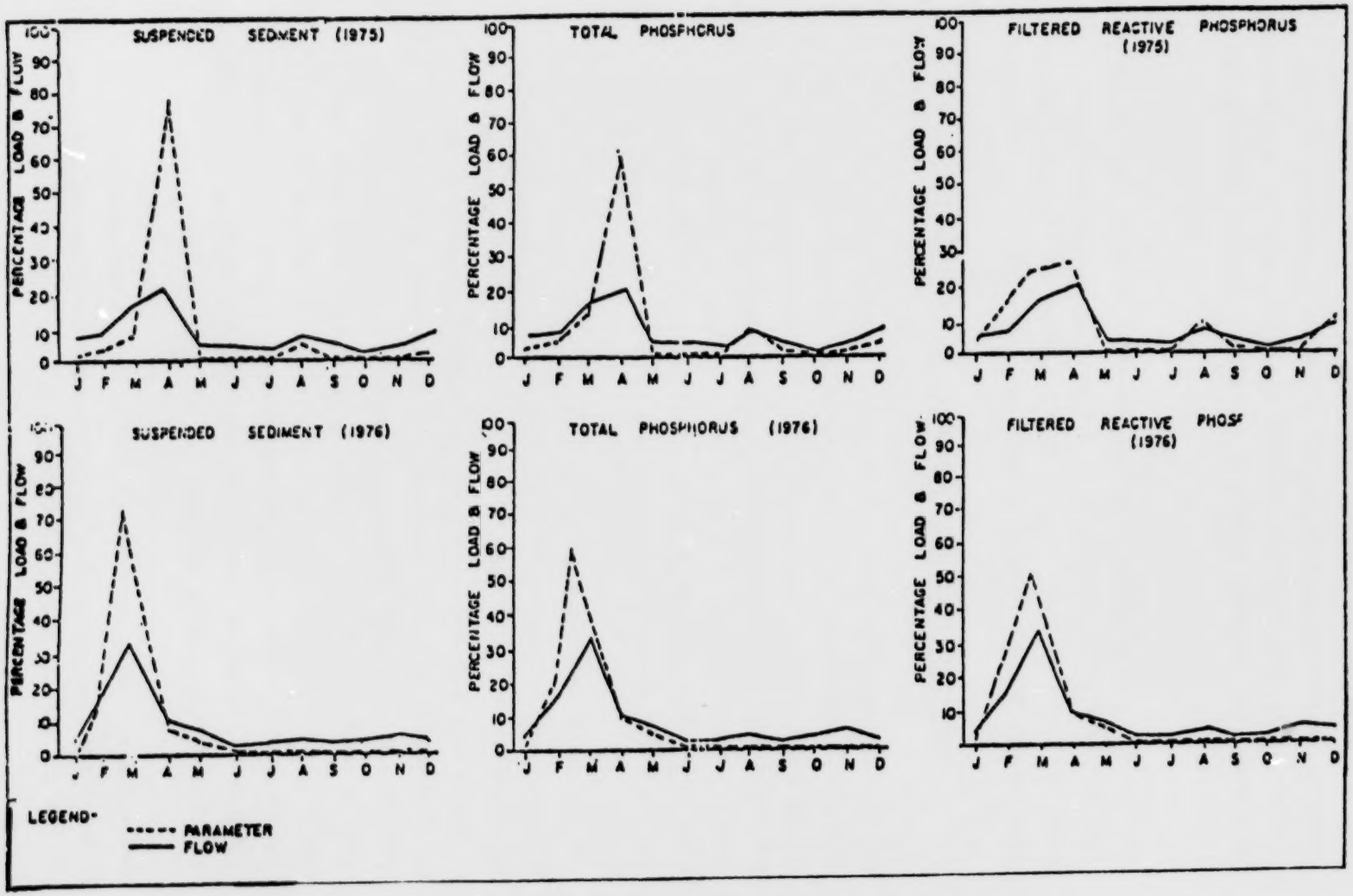


Figure 9. Monthly Percent Distribution of Pollutant loads of Suspended Solids, Total Phosphorus and Filtered Reactive Phosphorus for the Years 1975 and 1976 in the Nith River.

There is no precise definition of "hydrologically active area" as yet, although most scientists agree with the concept. Further, there is no precise methodology to define the boundaries of such areas. It appears that the sizes of the hydrologically active areas vary from year to year, depending on rainfall amount, duration and intensity.

Because of their proximity to channels and streams as well as their specific land characteristics, hydrologically active areas contribute most of the non-point source pollution to a watershed even though they may make up a small portion of it.

3.4 POLLUTANT LOADS FROM POINT AND NON-POINT SOURCES

As part of the PLUARG study an extensive monitoring network (37 stations) was installed in the Grand River basin (Figure 10). During the 2- year study period (1975-77), streamflow levels were monitored at each station and water samples were collected and analyzed for a variety of water quality parameters. These data (MOE, 1979) were used to compute total pollutant loads from point and non-point sources for most of the stations in the basin.

Two pollutant load computation methods were used: the Beale Ratio Estimator method (Whitt, 1977) and the load-flow regression method (Hore and Ostry, 1978). Where data permitted, two loading estimates were obtained with the Beale Ratio Estimator method: one based on two flow strata and the other based on three or more flow strata. Load estimates derived with the Beale Ratio Estimator method using three or more flow strata are used in this study. Whenever the available data did not allow for the application of this method, load estimates derived with the load-flow regression method were used. A comparison of these load computation methods can be found in Hore and Ostry, 1978; and Wall, et al, 1978.

Load estimates obtained for suspended solids, total phosphorus, filtered reactive phosphorus, total Kjeldahl nitrogen and filtered nitrite and nitrate are given in Table 3. The loads in Table 2 are

Figure 10. Stream Quality Monitoring Network in the Grand River Basin.

Table 2. Total Annual Loads (t/year) and Unit Area Loads (kg/ha/year)

STATIONS	STATION CODE	SUSPENDED SOLIDS	TOTAL PHOSPHORUS	FILTERED REACTIVE PHOSPHORUS	TOTAL KJELDAHL NITROGEN	FILTERED NITRATE & NITRITE
Grand River Main Stem:						
at Conc. Rd. 13 n-W of Marsville	GR-3	3835.1 (56.6)	17.6 (0.3)	1.9 (1.1)	166.7 (2.4)	151.2 (2.1)
1st Conc. Dnstr. Bellwood Lake Outlet	GR-13	4209.1 (51.3)	17.3 (0.2)	3.5 (0.1)	228.9 (2.7)	181.8 (2.2)
at Bridge W. of Winterbourne	UL-21	29360.6 (208.0)	62.8 (0.4)	12.7 (0.1)	404.3 (2.8)	825.0 (5.8)
at 1st Br. Dnstr. From Galt STP	UL-22	146235.8 (417.0)	274.2 (0.8)	72.9 (0.2)	1368.4 (5.6)	3083.5 (8.7)
at Hwy. No. 6 in Caledonia	GR-5	222963.2 (373.0)	411.3 (0.7)	77.7 (0.1)	2862.3 (4.7)	5323.1 (8.9)
Bridge at Dunville	GR-15	221604.6 (332.0)	532.4 (0.8)	95.4 (0.1)	2691.3 (4.0)	5598.3 (8.3)
TRIBUTARIES						
Canagagigue Cr. at Floradale	AG-4	895.4 (486.0)	1.5 (1.1)	0.5 (0.3)	8.2 (6.0)	30.3 (16.4)
Canagagigue Cr. Dnstr. of Elmira	GR-19	3530.9 (290.0)	13.7 (1.1)	6.5 (0.4)	70.1 (5.7)	203.0 (16.3)
Conestogo R. at Willington St. Drayton	GR-10	19838.6 (716.0)	25.4 (0.9)	5.5 (0.1)	103.8 (3.7)	127.9 (4.8)
Conestogo R. at Glen Allen	GR-12	12608.2 (223.0)	33.5 (0.6)	12.0 (0.2)	202.7 (3.5)	366.5 (6.4)
Conestogo R. at Hwy 85 in St. Jacobs	GR-14	21245.4 (274.0)	50.1 (0.6)	17.4 (0.2)	301.1 (3.8)	650.1 (8.3)
Speed R. N. of Rockwood	GR-8	233.9 (41.4)	0.5 (0.1)	0.1 (0.1)	11.4 (2.0)	20.0 (3.0)
Speed R. in Guelph	UL-2	1395.5 (50.1)	3.6 (0.3)	**	**	**
Eramosa R. in Guelph	UL-1	1203.1 (45.4)	4.1 (0.1)	**	**	**
Aberfoyle Cr. S.W. of Aberfoyle	EX-2	84.4 (26.6)	0.2 (0.1)	0.1 (0.1)	4.5 (1.3)	4.9 (1.5)
Nith R. N. of Shakespeare	GR-9	10065.8 (311.0)	40.5 (1.3)	13.9 (0.4)	151.6 (4.6)	408.7 (13.3)
Nith R. Dnstr. of Canning	GR-20	70208.2 (688.0)	124.4 (1.2)	25.4 (0.2)	531.5 (5.2)	1025.5 (19.0)
Whitemans Cr. N. of Hwy 53	GR-6	5412.3 (142.0)	14.9 (0.4)	3.9 (0.1)	119.2 (3.1)	446.6 (11.4)
McKenzie Cr. S. of Caledonia	Gr-7	3207 (158.0)	7.2 (0.4)	1.2 (0.1)	47.1 (2.7)	102.4 (4.4)

** Data are not available
( ) Unit area loads

from point sources (sewage treatment plants) and non-point sources (urban and rural). The annual loads of suspended solids, total phosphorus, filtered reactive phosphorus, total Kjeldahl nitrogen and filtered nitrite and nitrate from rural non-point sources are compared with those from urban point and non-point sources in Tables 4 to 8. These tables indicate that on an annual basis, non-point sources in the rural area supply 95% of suspended solids, 75% of total phosphorus, 64% of filtered reactive phosphorus, 60% of total Kjeldahl nitrogen and 92% of filtered nitrite and nitrate. However, due to the marked seasonality of nutrient transport, the agricultural contribution to nutrient production during the summer period (June - September) is reduced. For example, the agricultural portion of total phosphorus within the Grand River basin shifts from approximately 87% of the total load during the spring to about 45% in the summer months. The reduction is even more marked on some streams like the Speed River. Here, because of a high and relatively uniform sewage treatment plant loading, the agricultural portion of the total phosphorus production is reduced from approximately 33% in the spring to less than 6% during the summer months.

3.5 POLLUTANT LOADS FROM RURAL NON-POINT SOURCES

Pollutant loads contributed by rural diffuse sources in the Grand River basin were derived from the load estimates given in Table 3. The total annual load contributed by all sources within each sub-basin was obtained by subtracting the inlet load(s), estimated for the upstream station(s), from the outlet load, estimated for the downstream station. Since load estimates were not available for all inlet and outlet locations, total loads were sometimes computed for a group of sub-basins. Load contribution from rural diffuse sources was computed by subtracting loads from point sources and urban diffuse sources from the total annual load computed above. The results are summarized in Table 8 in terms of annual pollutant loads (t/year) and unit area loads (kg/ha/year).

The range of suspended solids unit area loads (kg/ha/year) spans more than two orders of magnitude. Low unit area loads (less than

Table 3. Distribution of Suspended Solid Loads Among Urban and Rural Sources in the Grand River Basin

Sub-basin	Stations Used to Calculate Sub-basin Loads	Total Loads t/yr	STP+ Urban Runoff Loads t/yr	Rural Diffuse Source Loads t/yr	Unit-Area Loads kg/ha/yr
Upper Grand					
GA0101 + GA0102	GR3	3885	5	2880	57.18
GA0103	GR3, GR13	324	0	324	24.15
Canagagigue Creek					
GA0105	AG4, GR19	2635	41	2594	251.20
GA0106	AG4	895	0	895	490.68
Conestogo River					
GA0601	GR10	19838	14	19824	723.89
GA0602	GR10, GR12	*	0	*	*
GA0603	GR12, GR14	8638	0	8638	416.10
Speed River					
GA0401	GR8	236	0	236	41.91
GA0402	GR8, UL2	1159	0	1159	52.96
GA05	UL1	1203	0	1203	45.92
GA0403 + GA0404 + GA0405 + GA0406 + GA0407	UL1, UL2, EX5	*	2227	*	*
Galt Creek					
GA0301 + GA0302 + GA0303	EX2	83	0	83	26.63
Middle Grand					
GA0104	GR13, GR19, UL21	21622	37	21585	459.88
GA0107 + GA0108 + GA0109 + GA0110 + GA0111 + GA0604 + GA0408	UL21, EX5, EX2 UL22, GR14	93786	11319	82467	971.9
Nith River					
GA0201	GR9	10065	0	10065	314.65
GA0202 + GA0203 + GA0204 + GA0205 + GA0206 + GA0207 + GA0208 + GA0209 +	GR9, GR20	60142	27	60115	862.71
Whitemans Creek					
GB0501	GR6	5413	0	5413	167.85
McKenzie Creek					
GB0201	GR7	3207	1	3207	207.32
Lower Grand					
GA0111 + GA0210 + GB0502 + GB0101 +	UL22, GR11, GR20, GR6	34795	220	34575	1162.11
GB04 + GB03 + GB0102 + GB0202	GR11, GR15	*	5025	*	*
TOTAL		367926	18915	351264	

* Negative values. Pollutant load computed for the outlet station is less than the sum of the pollutant loads computed for the inlet stations.

Table 4. Distribution of Total Phosphorus Loads Among Urban and Rural Sources in the Grand River Basin

Sub-basin	Stations Used to Calculate Sub-basin Loads	Total Load	STP+ Urban Runoff Loads	Rural Diffuse Source Loads	Unit-Area Loads
		t/yr	t/yr	t/yr	kg/ha/yr
Upper Grand					
GA0101 + GA0102	GR3	17.53	0.89	16.64	0.245
GA0103	GR3, GR13	*	0	*	
Canagaguie Creek					
GA0105	AG4, GR19	12.17	3.45	8.72	.844
GA0106	AG4	1.54	0	1.54	.844
Conestogo River					
GA0601	GR10	25.38	0.19	25.19	0.920
GA0602	GR10, GR12	7.15	0	7.15	0.251
GA0603	GR12, GR14	16.57	0	16.57	0.798
Speed River					
GA0401	GR8	0.46	0	0.46	0.082
GA0402	GR8, UL2	3.11	0	3.11	0.142
GA05	UL1	4.13	0	4.13	0.158
GA0403 + GA0404 + GA0405 + GA0406 + GA0407	UL1, UL2, EX5	*	17.33	*	
Galt Creek					
GA0301 + GA0302 + GA0303	EX2	0.22	0	0.22	0.071
Middle Grand					
GA0104	GR13, GR19, UL21	31.77	2.74	29.03	.619
GA0107 + GA0108 + GA0109 + GA0110 + GA0111 + GA0604 + GA0408	UL21, EX5, EX2, UL22, GR14	149.10	84.96	64.14	0.756
Nith River					
GA0201	GR9	40.49	0	40.49	1.266
GA0202 + GA0203 + GA0204 + GA0205 + GA0206 + GA0207 + GA0208 + GA0209 +	GR9, GR20	83.90	1.10	82.80	1.188
Whitemans Creek					
GB0501	GR6	14.87	0	14.87	0.395
McKenzie Creek					
GB0201	GR7	7.18	0	7.18	0.358
Lower Grand					
GA0111 + GA0210 + GB0502 + GB0101	UL22, GR11, GR20, GR6	2.46	2.68	*	*
GB04 + GB03 + GB0102 + GB0202	GR11, GR15	109.28	34.49	74.79	0.592
TOTAL		527.31	147.83	397.03	

* Negative values. Pollutant load computed for the outlet station is less than the sum of the pollutant loads computed for the inlet stations.

Table 5. Distribution of Filtered Reactive Phosphorus Loads Among Urban and Rural Sources in the Grand River Basin

Sub-basin	Stations Used to Calculate Sub-basin Loads	Total Loads t/yr	STP+ Urban Runoff Loads t/yr	Rural Diffuse Source Loads t/yr	Unit-Area Loads kg/ha/yr
Upper Grand					
GA0101 + GA0102	GR3	1.85	0.33	1.52	0.022
GA0103	GR3, GR13	1.60	0	1.60	0.119
Canagagigue Creek					
GA0105	AG4, GR19	5.95	1.31	4.64	0.449
GA0106	AG4	0.54	0	0.54	0.296
Conestogo River					
GA0601	GR10	5.46	0.07	5.39	0.197
GA0602	GR10, GR12	6.58	0	6.58	0.231
GA0603	GR12, GR14	5.40	0	5.40	0.260
Speed River					
GA0401	GR8	0.05	0	0.05	0.009
GA0402	GR8, UL2	-	-	-	-
GA05	UL1	-	-	-	-
GA0403 + GA0404 + GA0405 + GA0406 + GA0407	UL1, UL2, EX5	-	-	-	-
Galt Creek					
GA0301 + GA0302 + GA0303	EX2	.04	0	.04	0.013
Middle Grand					
GA0104	GR13, GR19, UL21	2.76	1.04	1.72	0.037
GA0107 + GA0108 + GA0109 + GA0110 + GA0111 + GA0604 + GA0408	UL21, EX5, EX2, UL22, GR14	42.79	27.90	14.89	0.113
Nith River					
GA0201	GR9	13.98	0	13.98	0.437
GA0202 + GA0203 + GA0204 + GA0205 + GA0206 + GA0207 + GA0208 + GA0209 +	GR9, GR20	11.43	0.42	11.01	0.158
Whitemans Creek					
GB0501	GR6	3.89	0	3.89	0.103
McKenzie Creek					
GB0201	GR7	1.75	0	1.75	0.087
Lower Grand					
GA0111 + GA0210 + GB0502 + GB0101 +	UL22, GR11, GR20, GR6	*	0.85	*	*
GB04 + GB03 + GR0102 + GB202	GR11, GR15	13.49	10.93	2.56	0.020
TOTAL		117.56	42.85	75.56	

* Negative values. Pollutant load computed for the outlet station is less than the sum of the pollutant loads computed for the inlet stations.

- Not available.

Table 6. Distribution of Total Kjeldahl Nitrogen Loads among Urban and Rural Sources in the Grand River Basin

Sub-basin	Stations Used to Calculate Sub-basin Loads	Total Loads t/yr	STP+ Urban Runoff Loads t/yr	Rural Diffuse Source Loads t/yr	Unit-Area Loads kg/ha/yr
Upper Grand					
GA0101 + GA0102	GR3	165.68	1.34	164.34	2.422
GA0103	GR3, GR13	62.00	0	62.00	4.627
Canagagigue Creek					
GA0105	AG4, GR19	62.00	24.80	37.20	3.602
GA0106	AG4	8.28	0	8.28	4.539
Conestogo River					
GA0601	GR10	102.93	4.06	98.87	3.610
GA0602	GR10, GR12	98.57	0	98.57	3.459
GA0603	GR12, GR14	98.74	0	98.74	4.757
Speed River					
GA0401	GR8	11.44	0	11.44	2.032
GA0402	GR8, UL2	-	-	-	-
GA05	UL1	-	-	-	-
GA0403 + GA0404 + GA0405 + GA0406 + GA0407	UL1, UL2, EX5	-	-	-	-
Galt Creek					
GA0301 + GA0302 + GA0303	EX2	3.95	0	3.95	1.267
Middle Grand					
GA0104	GR13, GR19, UL21	106.00	16.63	89.37	1.904
GA0107 + GA0108 + GA0109 + GA0110 + GA0111 + GA0604 + GA0408	UL21, EX5, EX2, UL22, GR14	1263.15	984.74	278.41	2.110
Nith River					
GA0201	GR9	151.24	0	151.24	4.728
GA0202 + GA0203 + GA0204 + GA0205 + GA0206 + GA0207 + GA0208 + GA0209 +	GR9, GR20	280.00	8.61	371.40	5.330
Whitemans Creek					
GB0501	GR6	119.00	0	119.00	3.159
McKenzie Creek					
GB0201	GR7	47.32	0	47.32	2.359
Lower Grand					
GA0111 + GA0210 + GB0502 + GB0101	UL22, GR11, GR20, GR6	*	12.81	*	*
GB04 + GB03 + GB0102 + GB0202	GR11, GR15	157.61	207.99	*	*
TOTAL		2737.91	1260.98	1640.13	

* Negative values. Pollutant load computed for the outlet station is less than the sum of the pollutant loads computed for the inlet stations.

- Not available.

Table 7. Distribution of Filtered Nitrite and Nitrate Loads Among Urban and Rural Sources in the Grand River Basin

Sub-basin	Stations Used to Calculate Sub-basin Loads	Total Loads t/yr	STP+ Urban Runoff Loads t/yr	Rural Diffuse Source Loads t/yr	Unit-Area Loads kg/ha/yr
Upper Grand					
GA0101 + GA0102	GR3	151.22	3.91	147.31	2.171
GA0103	GR3, GR13	30.59	0	30.59	2.28
Canagagigue Creek					
GA0105	AG4, GR19	172.67	8.85	163.82	15.860
GA0106	AG4	30.38	0	30.38	16.656
Conestogo River					
GA0601	GR10	127.90	1.65	126.25	4.610
GA0602	GR10, GR12	238.63	0	239.63	8.374
GA0603	GR12, GR14	283.63	0	283.63	13.664
Speed River					
GA0401	GR8	20.08	0	20.08	3.566
GA0402	GR8, UL2	-	-	-	-
GA05	UL1	-	-	-	-
GA0403 + GA0404 + GA0405 + GA0406 + GA0407	UL1, UL2, EX5	-	-	-	-
Galt Creek					
GA0301 + GA0302 + GA0303	EX2	4.90	0	4.90	1.572
Middle Grand					
GA0104	GR13, GR19, UL21	440.19	13.43	426.76	9.092
GA0107 + GA0108 + GA0109 + GA0110 + GA0111 + GA0604 + GA0408	UL21, EX5, EX2, UL22, GR14	1607.30	297.79	1309.51	9.920
Nith River					
GA0201	GR9	408.76	0	408.76	12.779
GA0202 + GA0203 + GA0204 + GA0205 + GA0206 + GA0207 + GA0208 + GA0209	GR9, GR20	616.80	2.08	614.72	8.822
Whitemans Creek					
GB0501	GR6	446.68	0	446.68	11.856
McKenzie Creek					
B G0201	GR7	102.50	0	102.50	5.109
Lower Grand					
GA0111 + GA0210 + GB0502 + GB0101	UL22, GR11, GR20, GR6	611.61	1.14	610.47	20.530
GB04 + GB03 + GB0102 + GB0202	GR11, GR15	328.46	106.88	221.58	1.760
TOTAL		5622.30	435.73	5186.57	

- Not available.

Table 8. Annual Pollutant Loads (t/year) and Unit Area Loads (kg/ha/year) Contributed by Rural Non-Point Sources

SUB-BASIN LOCATION	SUB-BASIN CODE	AREA ha	SUSPENDED SOLIDS	TOTAL PHOSPHORUS	FILTERED REACTIVE PHOSPHORUS	TOTAL KJELDAHL NITROGEN	FILTERED NITRITE & NITRATE
Grand River Main Stem							
above Lake Belwood	GA0101 and GA0102	67848	3880.2 (57.2)	16.6 (0.2)	1.5 (0.1)	164.3 (2.4)	147.3 (2.7)
above Shand Dam	GA0103	13245	324.4 (24.2)	**	1.6 (0.1)	62.0 (4.6)	30.6 (2.3)
above West Montrose	GA0104	36326	21585.8 (459.9	29.0 (0.6)	1.7 (0.1)	89.4 (1.9)	426.8 (9.1)
above Cambridge	GA0107, GA0108, GA0109, GA0110, GA0604 & GA0408	69403	82467.1 (971.9)	64.1 (0.8)	14.9 (0.1)	278.4 (2.1)	1309.5 (9.9)
above Brantford	GA0111, GA0210, GB0502, & GB0101	29113	34575.5 (1162.5)	**	**	**	610.5 (20.5)
below Brantford	GB04, GB03, GB0102 &GB0202	127683	**	74.8 (0.6)	2.6 (0.0)	**	221.6 (1.8)
TRIBUTARIES							
Canagagigue Cr. above Flordale	GA0106	1824	895.3 (490.7)	1.5 (0.8)	0.5 (0.3)	8.3 (4.5)	30.4 (16.7)
Canagagigue Cr. below Flordale	GA0105	8812	2594.2 (251.2)	8.7 (0.8)	4.6 (0.4)	37.2 (3.6)	163.8 (15.9)
Conestogo R. above Conestogo Lake	GA0601	27386	19824.6 (723.9)	25.2 (0.9)	5.4 (0.2)	98.9 (3.6)	126.3 (4.6)
Conestogo R. above Conestogo Dam	GA0602	28496	**	7.2 (0.3)	6.6 (0.2)	98.6 (3.5)	238.6 (8.4)
Conestogo R. below Conestogo Dam	GA0603	20757	8638.5 (416.1)	16.6 (0.8)	5.4 (0.3)	98.7 (4.8)	283.6 (13.7)
Speed R. above Guelph	GA0401, GA0402	27522	1395.5 (50.7)	3.6 (0.1)	0.1 (0.0)	11.4 (2.0)	20.1 (3.6)
Speed R. below Guleph	GA0403, GA0404, GA0405 GA0406 & GA0407	9267	**	**	**	**	**
Eramosa R. above Guelph	GA05	26198	1203.4 (45.9)	4.1 (0.2)	**	**	**
Aberfoyle Cr. above Aberfoyle	GA0301	3117	83.8 (26.6)	0.2 (0.1)	0.1 (0.1)	4.0 (1.3)	4.9 (1.6)
Nith R. N. of Shakespeare	GA0201	31988	10065.2 (314.7)	40.5 (1.3)	14.0 (0.4)	151.2 (4.7)	408.8 (12.8)
Nith R. at Canning	GA0202, GA0203, GA0204, GA0205, GA0206, GA0207, GA0208 & GA0209	71751	60115.2 (862.7)	82.8 (1.2)	11.1 (0.2)	371.4 (5.3)	614.7 (8.8)
Whiteman Cr.	GB0501	37674	5413.1 (167.9)	14.9 (0.4)	3.9 (0.1)	119.0 (3.2)	446.7 (11.9)
McKenzie Cr.	GB0201	20063	3207.0 (207.3)	7.2 (0.4)	1.8 (0.1)	47.3 (2.4)	102.5 (5.1)

** Data are not available
( ) Unit area loads

200 kg/ha/year) are observed at the upper Grand River above Shand Dam, the Eramosa River and the Speed River above Guelph, Aberfoyle Creek and Whitemans Creek. High unit area loads (greater than 500 kg/ha/year) are observed at the Conestogo River above Conestogo Lake, the Nith River at Canning and the Grand River above Brantford.

The unit area loads of total phosphorus range from 0.1 to 1.3 kg/ha/year. High total phosphorus unit area loads are found in those sub-basins with high suspended solids unit area loads. Low total phosphorus unit area loads are found in those sub-basins with low suspended solids unit area loads. This pattern can be attributed to the strong association between phosphorus and suspended solids.

The range of total Kjeldahl nitrogen unit area loads is small (1.3 to 5.3 kg/ha/year) relative to those of suspended solids and total phosphorus. Total Kjeldahl nitrogen unit area loads exceed 3.5 kg/ha/year in the Grand River above Shand Dam, the Conestogo River, the Nith River, Canagagique Creek and McKenzie Creek.

The distributions of rural diffuse source pollution loads by sub-basin are illustrated in Figures 11 to 15.

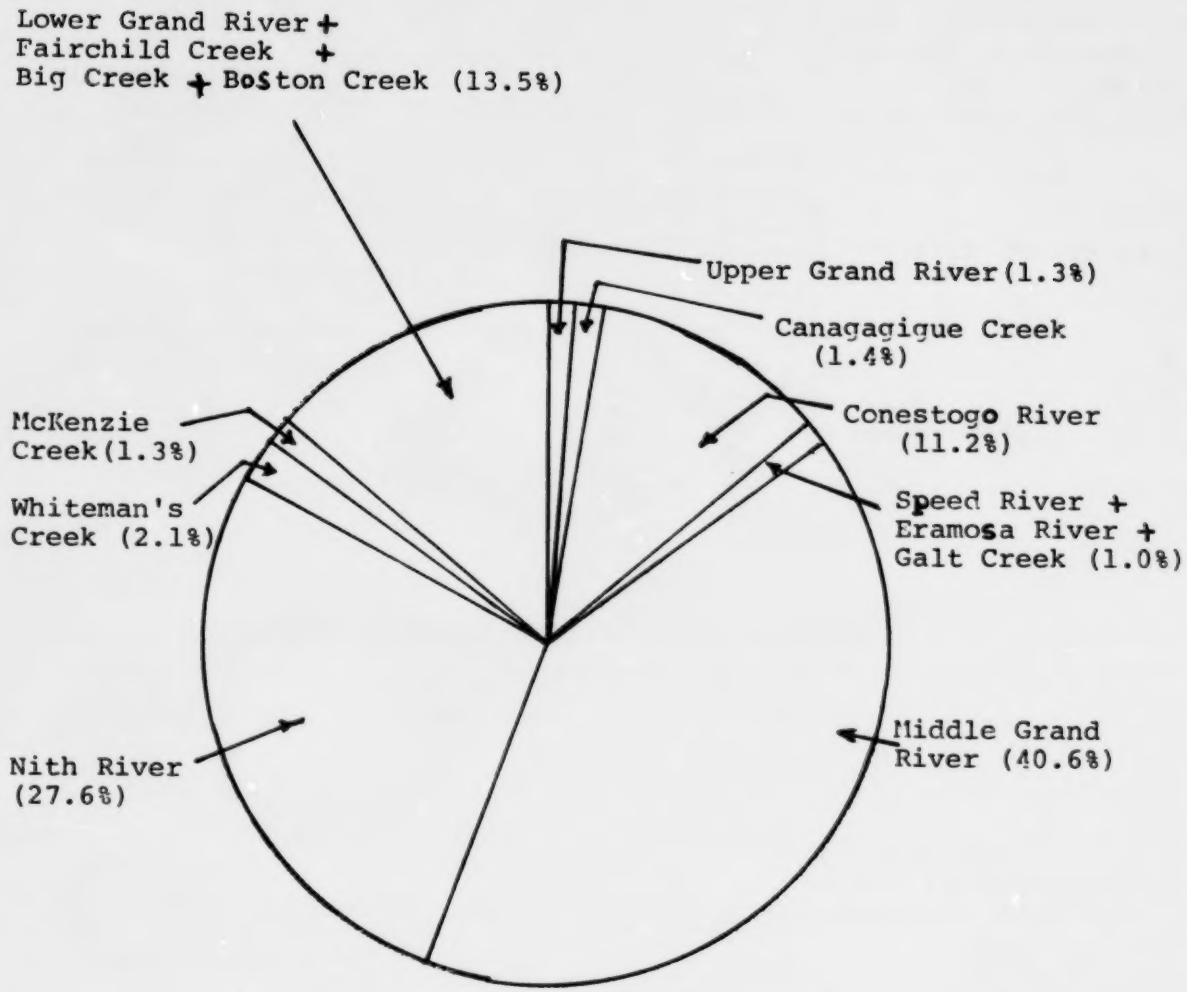


Figure 11. Distribution of Suspended Solid Loads Contributed by Rural Diffuse Sources.

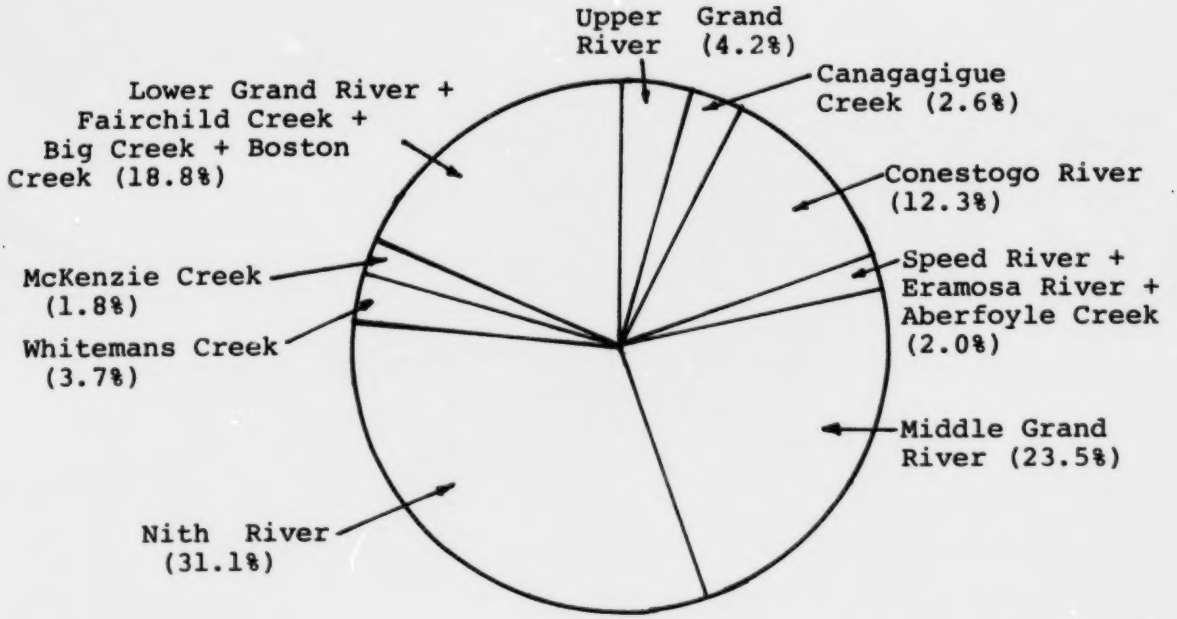

Upper Grand River (4.2%)
Canagagigue Creek (2.6%)
Conestogo River (12.3%)
Speed River + Eramosa River + Aberfoyle Creek (2.0%)
Middle Grand River (23.5%)
Nith River (31.1%)
Whitemans Creek (3.7%)
McKenzie Creek (1.8%)
Lower Grand River + Fairchild Creek + Big Creek + Boston Creek (18.8%)

Figure 12. Distribution of Total Phosphorus Loads Contributed by Rural Diffuse Sources

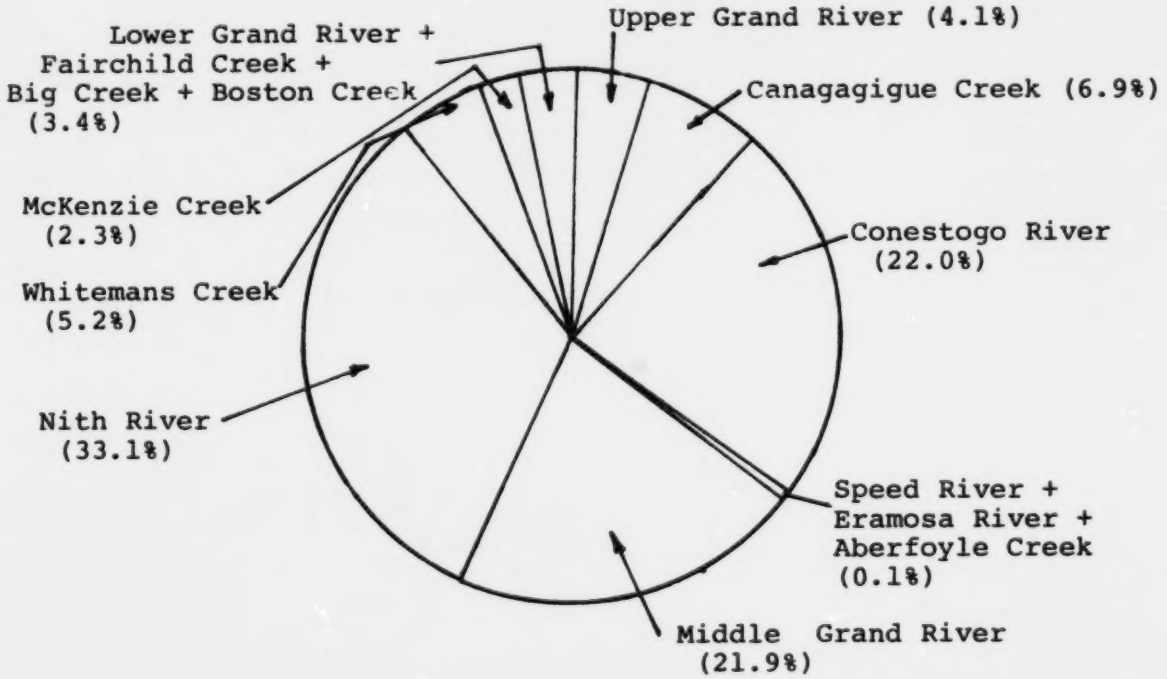

Upper Grand River (4.1%)
Canagagigue Creek (6.9%)
Conestogo River (22.0%)
Speed River + Eramosa River + Aberfoyle Creek (0.1%)
Middle Grand River (21.9%)
Nith River (33.1%)
Whitemans Creek (5.2%)
McKenzie Creek (2.3%)
Lower Grand River + Fairchild Creek + Big Creek + Boston Creek (3.4%)

Figure 13. Distribution of Filtered Reactive Phosphorus Loads Contributed by Rural Diffuse Sources.

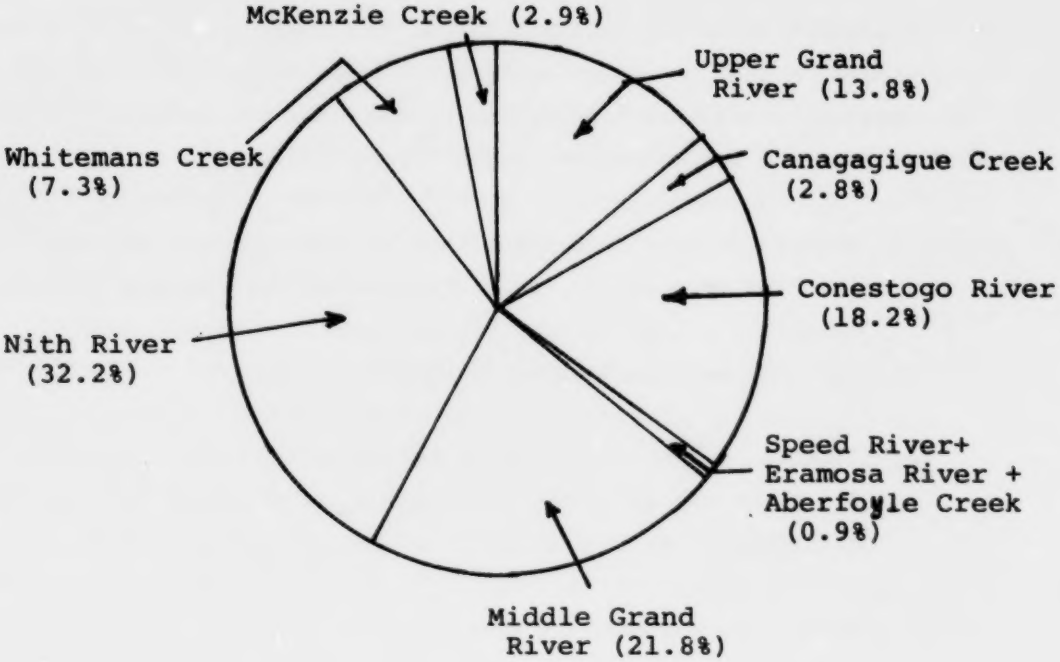


Figure 14. Distribution of Total Kjeldahl Nitrogen Loads Contributed by Rural Diffuse Sources

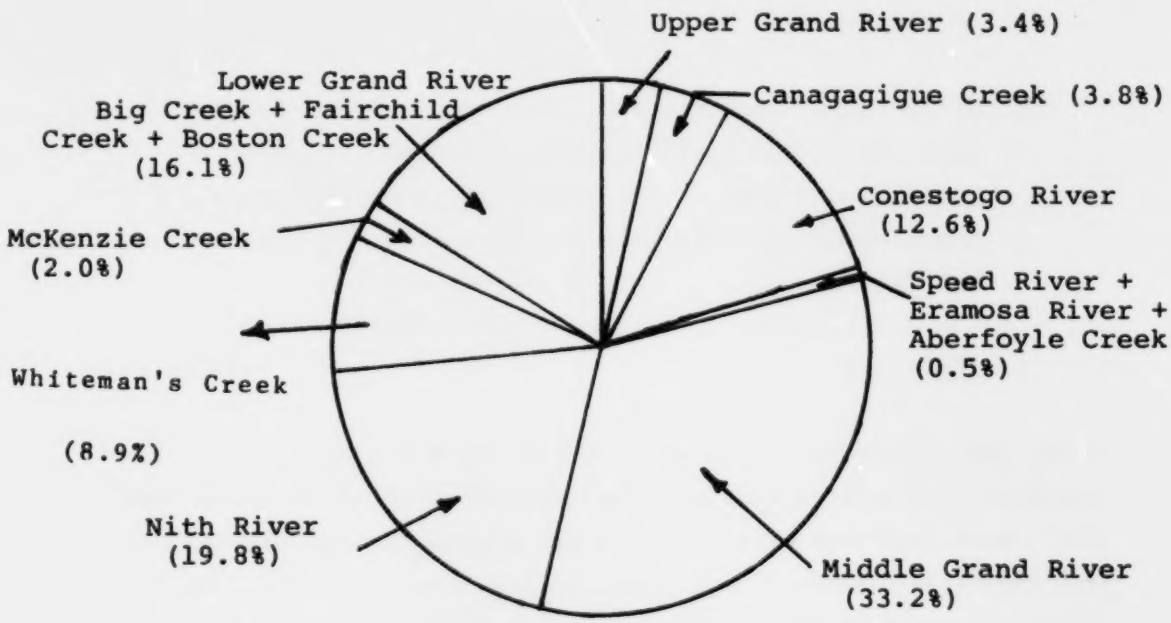

Upper Grand River (3.4%)
Lower Grand River Big Creek + Fairchild Creek + Boston Creek (16.1%)
Canagagigue Creek (3.8%)
Conestogo River (12.6%)
McKenzie Creek (2.0%)
Speed River + Eramosa River + Aberfoyle Creek (0.5%)
Whiteman's Creek (8.9%)
Nith River (19.8%)
Middle Grand River (33.2%)

Figure 15. Distribution of Filtered Nitrite and Nitrate Loads Contributed by Rural Diffuse Sources.

4.0 EVALUATION OF CAUSES OF AGRICULTURAL POLLUTION

The causes of agricultural pollution in the Grand River basin can be divided into the following four major categories:

1) Effects of land form which include soil texture, soil type (mineral or organic), surficial geology (soil parent materials), physiography (slope, natural drainage density), soil chemistry and stream bank conditions.

2). Effects of agricultural land use intensity which include the types and distribution of crops and the types and distribution of livestock and livestock operations.

3) Effects of agricultural practices (management) which include the nature and timing of tillage methods, crop rotation, strip cropping, contour ploughing, buffer zone, stream bank stabilization, the type and intensity of artificial drainage, the amount and timing of fertilizer and manure application, and the type and amount of pesticides used.

4) Effects of climate which include meteorological factors that affect the runoff and erosion processes such as rainfall intensity and duration, frequency of storms, snow accumulation and melt, and the antecedant precipitation period.

4.1 EFFECTS OF LAND FORM

As was mentioned earlier, it was found during the PLUARG study (Sonzogni et al, 1980) that among all land form characteristics, the single most important factor that causes nonpoint source pollution problems is soil texture (soil particle size distribution). The volume and rates of surface runoff are functions of the degree of imperviousness. Since fine grained clay soils are more impervious than coarse sandy soils, they tend to produce more surface runoff

and to contribute at the same time larger amounts of clay sized particles which can be easily transported with the flow. These clay particles would serve as a vehicle to carry other pollutants such as phosphorus, heavy metals and pesticides. Coarse sandy soils on the other hand allow for the rapid infiltration of water and consequently produce low surface runoff and smaller suspended solid and associated pollutant loads.

The potential for pollutant movement to receiving water is also dependant on other land form characteristics such as surficial geology, topography and drainage density. Surficial geology along with climate explains the origins of land forms and constitute the parent materials on which soils develop. Different topographic conditions produce different pollution loads. For example, high lands with steep slopes are more prone to erosion than flat low lands. Drainage density reflects climatic conditions which were prevalent in the basin and the degree of maturity of the river system. The conditions of stream banks play an important role in determining the magnitude of stream bank erosion.

4.2 EFFECTS OF AGRICULTURAL LAND USE

The magnitude of pollution loads from agricultural land is dependant on the types and distribution of crops, livestock and livestock operations. It was found during the PLUARG study (Sonzogni et al, 1980) that permanent pasture, hay, small grains, corn in rotation, continuous corn, white beans and similar cash crops, some horticultural crops, and ploughed land have progressively greater erosion potential.

The types and distribution of livestock operations including feedlot significantly add to the pollution potential of land specifically in terms of nutrients (phosphorous and nitrogen).

4.3 EFFECTS OF AGRICULTURAL PRACTICES

Any agricultural practice that exposes soil to the natural erosive forces (rain, runoff and wind) represents an erosion and pollution hazard. The thrust of good agricultural practices is to protect the land resources base and to hold rainfall on the land in the soil where it cannot contribute to floods, erosion and sedimentation problems. In doing so, benefits accrue to other purposes, namely, improved water quality in receiving streams. In general, the greater the canopy and ground cover protection, the lower the pollution potential.

Among the important agricultural practices that affect the nonpoint source pollution are the nature and timing of tillage methods, specifically tall ploughing. The fall tillage practice exposes the soil over the winter thereby provides greater opportunity for erosion. Minimum tillage (or no-tillage), contour ploughing, strip cropping, crop rotation and crop residue management are among the non-structural remedial measures that could result in much reduced erosion.

Stream and ditch bank erosion also contribute to pollution loads. Studies conducted by PLUARG (Wall et al, 1978) estimated that materials from eroded banks constitute from 2% to 33% of the total sediment load.

Tile drainage is an extremely important tool available to the farmer to drain wet soils and it is being utilized increasingly in the Grand River basin. Most pollutants are expected to have a lower percentage of total transport in tile drainage with only one significant exception - nitrogen in the nitrate form.

Other important factors which contribute to nonpoint source pollution from agricultural land are fertilizers, animal manure and

pesticides. The majority of soluble nitrogen in runoff is derived from fertilizers. The increase in pollution loads when fertilizers are properly applied is minimal. However, practices that fail to incorporate fertilizers into the soils tend to increase the loss of fertilizers to surface runoff. Further, application of fertilizers in excess of that needed for optimum plant growth constitutes an economic loss and an environmental hazard.

Spreading of manure on snow-covered soils exposes the material to runoff during snowmelt periods and leads to increased soluble nutrients in receiving water. Livestock access to streams also causes problems in terms of direct pollution and undermining stream banks.

Pesticides including insecticide, fungicide, herbicide and rodenticide are applied in varying quantities to almost all types of land in the Grand River basin. These chemicals can be carried to the streams along with detached soil particles. The PLUARG study indicates that only a limited number of pesticides were detected in the Grand River basin. Levels were generally too low to calculate precise pesticide load estimates (Sonzogni et al, 1980).

4.4 EFFECTS OF CLIMATE

Total pollution loads on an annual basis as well as unit area loads from agricultural land are directly related to the precipitation - runoff process. This includes the type of precipitation (rain or snow), the intensity, duration and frequency of storms, snow accumulation and melt as well as the length of the antecedant precipitation period. These variations in the magnitude of loads occur even if all the other factors such as land forms and land uses remain unchanged. For example, measurements of pollutant loads at various stations within the Grand River basin during the year of 1975 were different from those measured in 1976 notwithstanding that neither land forms, land uses nor agricultural practices did change significantly during this period. What did change, however, were

the above mentioned meteorological factors. The importance of climate is reflected by the rainfall factor included in the universal soil loss equation. This factor represents the kinetic energy of the raindrop which causes the detachment of soil particles.

5 DATA COLLECTION PROGRAM

During the Grand River Basin Water Management Study, two field surveys were carried out. In addition, aerial photographs were used to identify livestock operations within a 300 m strip of land along the banks of the Nith, Conestogo and Grand Rivers and their tributaries (Table 9).

5.1 FIELD SURVEY, 1978

The first field survey, conducted in the summer of 1978, covered parts of the Nith River basin, most of the Conestogo River and Irvine Creek basins, the middle Speed River and Eramosa River basins, the lower Fairchild Creek basin, and the middle McKenzie Creek basin (Figure 16). During the survey, estimates were made of the widths of buffer strips and the percentages of unvegetated banks (which was assumed to indicate the degree of bank erosion). Locations of manure piles draining directly into streams, and cattle access to stream channels were noted. In addition, good management practices as well as management problems were identified. The results of this field survey are given in Table 10. A detailed description of this program is given by G. Neilson (1978).

A total of 273 sites were investigated. At these sites, the widths of the buffer strips ranged from less than 2.0 m to over 30.0 m. Approximately 25.0% of the sites had a buffer strip width of less than 3.0 m. A surprisingly large number of examined sites (55.0%) has a buffer strip width exceeding 30.0 m.

The degree of bank erosion was evaluated at all sites. No evidence of bank erosion was found at approximately 47.0% of the sites. Another 35.0% of the sites showed slight evidence of bank erosion; 16.0% of the sites had a high degree of bank erosion and about 1.0% had a severe bank erosion problem. These later sites were located in the Conestogo River basin.

Table 9. Number of Livestock Operations in Areas Adjacent to Streams in the Northwestern Part of the Grand River Basin Based on Aerial Photographs Interpretation

Sub-Basin Location	Sub-Basin Code	Cattle Operations within 90.0 m	Cattle Operations within 300.0 m	Other Livestock Within 90.0 m	Other Livestock Within 300.0 m
GRAND RIVER MAIN STEM					
above Lake Belwood	GA0102	5	92	0	2
above Shand Dam	GA0103	3	18	0	0
above West Montrose	GA0104	23	128	0	0
above Cambridge	GA0107	5	65	0	0
TRIBUTARIES					
Canagagigue Cr. above Flordale	GA0106	5	22	0	0
Canagagigue Cr. below Flordale	GA0105	7	66	0	0
Conestogo R. above Conestogo Lk.	GA0601	10	122	0	0
Conestogo R. above Conestogo Dam	GA0602	8	118	0	5
Conestogo R. below Conestogo Dam and	GA0603 GA0604	38	211	0	2
Nith R. N. of Shakespeare	GA0201	33	176	0	3
Nith R. at Canning GA0205, GA0206, GA0209 and	GA0202 GA0210	48	196	0	1

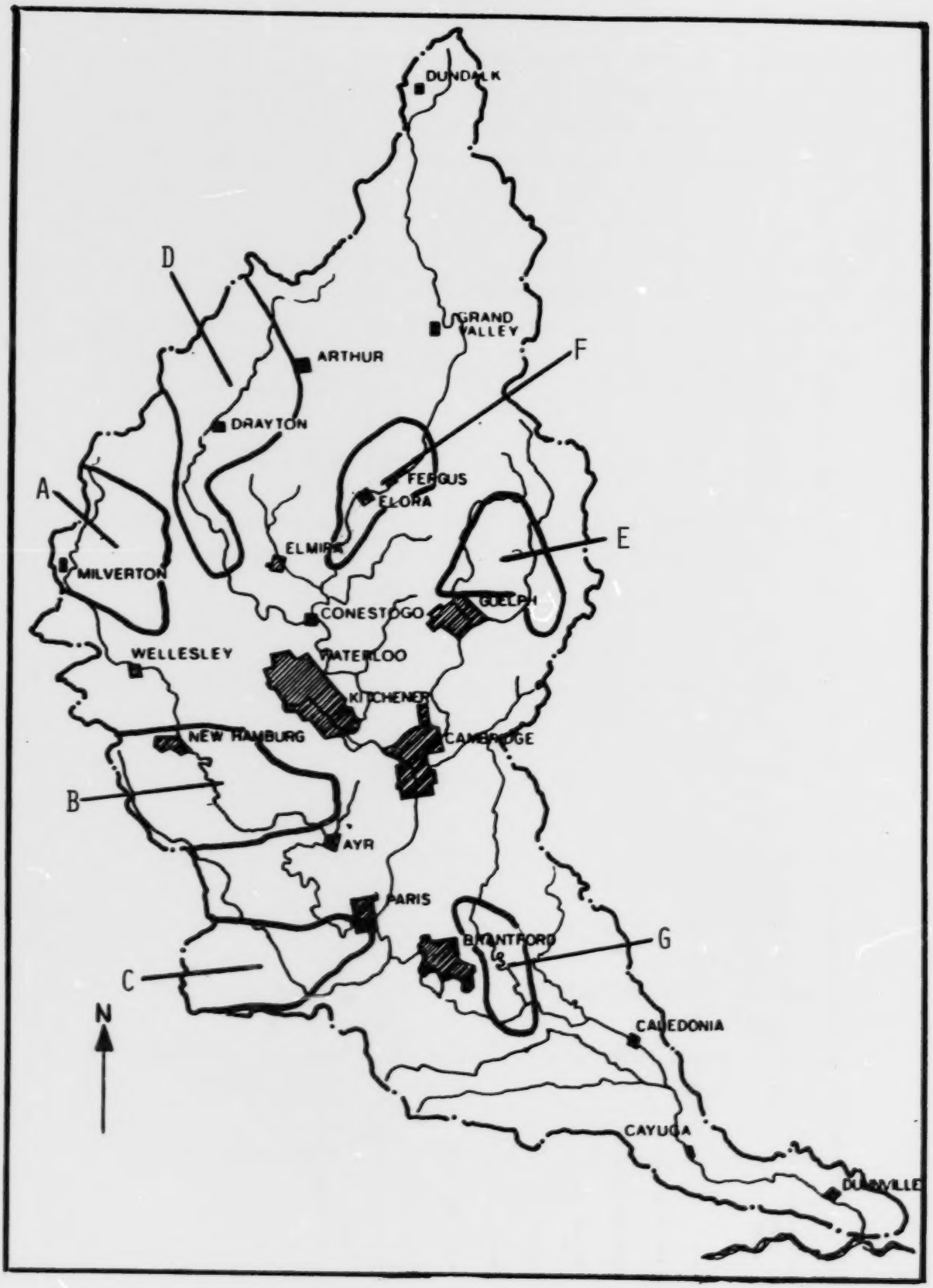


Figure 16. Areas Investigated in the 1978 Field Survey.

Table 10. Summary of 1978 Field Survey Results (Expressed as Number of Sites in Each Classification)

RIVER BASINS	ZONES	# OF SITES	BUFFER STRIP (m)					EVIDENCE OF BANK EROSION				MANURE PILES DRAIN TO CREEK	CATTLE WITH STREAM ACCESS	CROPS UP & DOWN SLOPE	STRIP CROPPING
			0-2	2-3	3-6	6-30	over 30	None	Slight	Medium	Severe				
Upper Nith River	A	46	13	9	9	1	14	14	17	15	0	5	15	5	0
Lower Nith River	B	47	7	7	2	6	25	23	16	8	0	9	25	13	2
Whiteman Creek	C	48	3	6	6	7	26	28	15	5	0	2	8	24	3
Conestogo River	D	57	4	5	6	3	39	16	28	10	3	9	24	15	2
Speed and Eramosa R.	E	33	1	0	2	2	28	27	6	0	0	0	3	5	0
Middle Grand River	F	24		3	5	2	13	11	9	4	0	2	5	2	0
Fairchild Creek	G	18	6	2	1	4	5	10	6	2	0	0	1	7	1
Total		273	35	32	31	25	150	129	97	44	3	27	91	71	3

A total of 27 sites had manure piles draining directly to streams. Most of these sites were located in the Conestogo River and the Nith River basins. Cattle access to stream channels were sited at 81 sites, most of which again were located in the Conestogo River and the Nith River basins.

Non-contour ploughing (up and down slope) was observed at 71 sites, most of which were noted in the lower Nith River and the Conestogo River basins. On the other hand, seven out of eight total observed sites that had strip cropping - a good agricultural practice - were located in these same basins.

5.2 FIELD SURVEY, 1979

The second survey was carrried out during the summer of 1979 in the Nith River, the upper Conestogo River and the Irvine Creek (Figure 17). During this survey, the following items were investigated:

Bank stability: actively unstable, potentially unstable and stable,

Bank slope: steep, moderate and small,

Bank shape: concave, convex, uniform and complex,

Bank height: less than 2.0 m, 2.0-5.0 m, and over 5.0 m,

Vegetation cover: 0-10%, 10-25%, 25-50%, 50-75% and over 75%,

Buffer width of floodplain and adjacent fields: none, 0-3.0 m and over 3.0 m, cropped land,

Land use in flood plain: no flood plain, woods, pasture, small grains, row crops and other,

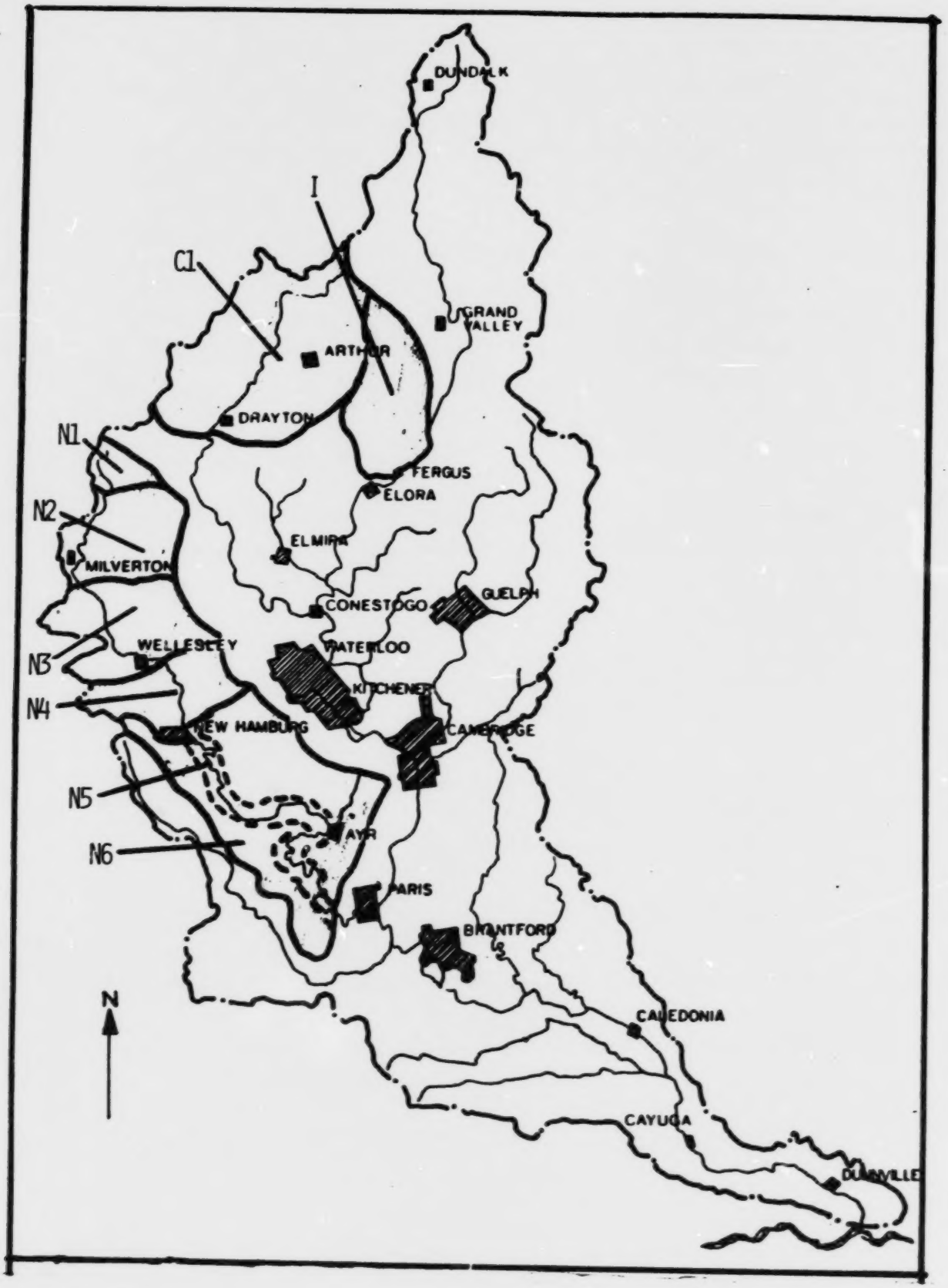


Figure 17. Areas Investigated in the 1979 Field Survey.

Cropping practices in floodplain: crop rotation, up and down slope cropping, fall plough and fall application of fertilizer,

Land use in adjacent fields: woods, pasture, small grains, row crops and other,

Cropping practices in adjacent fields: crop rotation, up and down slope cropping, fall plough and fall application of fertilizer,

Feedlots or manure storage in floodplain: none within 5.0 m, within 15.0 m, within 30.0 m and more than 30.0 m,

Cattle access to streams,

Conditions of tile outlets: no problem or a problem.

The results of this survey are presented in Table 11 for the eight investigated zones in terms of percentages. A detailed description of the survey is given by H. MacDonald (1979).

The survey indicated that the majority of all the stream banks investigated are stable and only a small percentage are actively unstable.

A small fraction (less than 8%) of all the sites investigated have no buffer zone whereas most sites have a buffer zone of over 3.0 m in width. Most cropped lands, however, have a buffer zone less than 3.0 m in width.

Land use in the flood plain is mostly woods and pasture except for the middle Nith River (Zones: N4, N5 and N6) where a small percentage of the flood plain (up to 23.0%) is used for small grains and row crops production.

Table 11. Summary of 1979 Field Survey Results (Expressed as Percentage of Sample Sites in Each Classification)

RIVER BASINS	ZONE	BANK STABILITY			BANK SLOPE			BANK SHAPE				BANK HEIGHT(m)			VEGETATION COVERAGE				
		Actively Unstable	Potentially Unstable	Stable	Steep	Moderate	Small	Concave	Convex	Uniform	Complex	>5	2-5	<2	0-10%	10-25%	25-50%	50-75%	>75%
Upper Nith River	N1	14	9	77	63	37	0	12	65	65	8	0	68	32	0	8	0	8	84
Upper Nith River	N2	20	28	53	39	39	21	24	24	48	5	3	45	52	11	5	0	24	61
Upper Nith River	N3	20	25	55	35	42	23	23	2	67	7	5	37	58	9	2	5	21	63
Upper Nith River	N4	14	20	67	42	25	33	6	8	78	8	11	31	58	0	11	5	25	58
Lower Nith River	N5	20	20	60	41	32	27	22	11	63	4	20	22	59	2	17	15	20	46
Lower Nith River	N6	6	3	90	19	37	44	34	32	29	5	0	13	87	5	0	3	2	90
Upper Conestogo River	C1	21	10	69	35	46	19	31	21	42	6	10	11	79	22	2	6	15	55
Irvine Creek	I	18	24	58	32	58	10	30	28	40	2	2	34	64	2	14	20	2	62

Table 11 (Cont'd)

RIVER BASINS	ZONE	BUFFER WIDTH (m) OF FLOODPLAINS & ADJ. FIELDS			BUFFER WIDTH > 3m FOR CROPPED LAND
		NONE	0-3	>3	
Upper Nith River	N1	8	29	63	23
Upper Nith River	N2	3	37	61	18
Upper Nith River	N3	2	49	49	0
Upper Nith River	N4	0	33	67	10
Lower Nith River	N5	2	16	82	30
Lower Nith River	N6	0	19	81	37
Upper Conestogo River	C1	0	3	97	44
Irvine Creek	I	0	4	96	45

Table 11 (Cont'd)

RIVER BASINS	Zone	No Floodplain	Land Use in Floodplain						Cropping Practices in Floodplain			
			Other	Woods	Pasture	Small Grains	Row Crop	Small Grains & Row Crop	Crop Rotation	Up/Down Slope Cropping	Fall Plough	Fall Application of Fertilizer
Upper Nith River	N1	17	0	100	0	0	0	0	0	0	0	0
Upper Nith River	N2	55	0	100	0	0	0	0	0	0	0	0
Upper Nith River	N3	57	0	12	88	0	0	0	0	0	0	0
Upper Nith River	N4	8	12	15	54	7	12	19	64	50	64	17
Lower Nith River	N5	17	2	27	48	5	18	23	35	0	0	0
Lower Nith River	N6	58	0	12	69	14	5	19	38	0	0	0
Upper Conestogo River	C1	61	3	8	89	0	0	0	0	0	0	0
Irvine Creek	I	64	0	17	83	0	0	0	0	0	0	0

Table 11 (Cont'd)

RIVER BASINS	Zone	Land Use in Adjacent Field						Cropping Practices in Adjacent Field			
		Other	Woods	Pasture	Small Grains	Row Crop	Small Grains & Row Crop	Crop Rotation	Up/Down Slope Cropping	Fall Plough	Fall Application of Fertilizer
Upper Nith River	N1	4	0	62	17	17	34	57	0	100	0
Upper Nith River	N2	3	0	38	34	25	59	100	0	100	0
Upper Nith River	N3	23	0	53	19	5	24	68	3	100	12
Upper Nith River	N4	17	14	36	8	25	33	70	8	74	42
Lower Nith River	N5	15	20	13	15	37	52	75	13	44	0
Lower Nith River	N6	10	26	28	18	18	36	91	17	100	0
Upper Conestogo River	C1	6	10	57	16	11	27	87	9	85	0
Irvine Creek	I	0	16	50	22	12	34	75	4	100	0

Table 11 (Cont'd)

RIVER BASINS	ZONE	CATTLE ACCESS A PROBLEM	FEEDLOTS OR MANURE STORAGE IN FLOODPLAIN				TILE OUTLETS A PROBLEM
			None	Within 5m	Within 15m	Within 30m	Over 30m	
Upper Nith River	N1	4	100	0	0	0	0	100
Upper Nith River	N2	39	97	0	3	0	0	31
Upper Nith River	N3	23	95	0	0	0	5	20
Upper Nith River	N4	14	94	0	3	3	0	23
Lower Nith River	N5	24	96	0	0	0	0	10
Lower Nith River	N6	15	100	0	0	0	0	9
Upper Conestogo River	C1	51	92	0	2	0	6	25
Irvine Creek	I	14	96	0	0	0	4	33

It was observed that crop rotation is practised to a substantial degree in the middle Nith River (Zones: N4, N5 and N6). Fall ploughing, up and down slope cropping and fall application of fertilizer were observed in Zone N4.

Land use in the fields adjacent to the flood plain is mostly pasture (up to 62.0%). Small grains and row crops are also significant, ranging from 24.0% to 59.0%. Crop rotation and fall ploughing are practiced widely in these fields. Up and down slope cropping was noticed in most zones but constituted a problem only in zones N5 and N6 where 13.0% to 17.0% of the fields, respectively, had up and down slope cropping.

Feedlots or open manure storages were observed in a very few places in the survey area. However, cattle access to streams was a problem in the Conestogo River (Zone C1) and the upper Nith River (Zone N2).

Tile outlets in disrepair occur in all survey zones but they are most abundant in the upper Nith River (Zone N1).

6 EVALUATION OF THE RELATIONSHIPS BETWEEN OBSERVED POLLUTANT LOADS AND THE CAUSES OF NON-POINT SOURCE POLLUTION

As was mentioned earlier, there are many important factors that influence the magnitude of nonpoint source pollution. Some of these factors are natural such as climate and land forms, whereas others are man-related, such as agricultural land use and management practices. It is evident that the least amount of pollution should be expected from lands with favourable natural conditions and good agricultural management. The worst combination, on the other hand, is unfavourable natural conditions and poor management. Given these facts, an attempt will be made to evaluate the relationships between the observed pollutant loads at various locations in the Grand River basin and the causes of nonpoint source pollution. Description of land use within various watersheds is based. On data available for the farm land within each watershed. No data on land use were available for those parts of the watershed which were not classified as farm land.

6.1 UPPER GRAND RIVER

This area of approximately 81000 ha constitutes the upper part of the Grand River basin and includes sub-basin GA0101, GA0102 and GA0103 (Figure 18). The surface area is made up mainly of clay till except in the surroundings of Belwood Lake where sand material occurs. The topography is gently rolling with steep slopes occurring along the sides of the larger creeks. Slopes are short and irregular. Most of the area is part of the Dundalk till plain physiographic unit and the remaining smaller area is part of the Hillsburgh sand hills physiographic unit. The most prominent soil series in this area are the Huron series. Other minor soil series are Perth, Brookston, Harriston, Listowel, Parkhill and Hillsburgh soils. With the exception of the Hillsburgh sandy soils, all the surface soils are loam or silt loam. This is due to the presence of a material, probably wind borne, which overlies the till. The physical effect of this material, which is more pervious than the

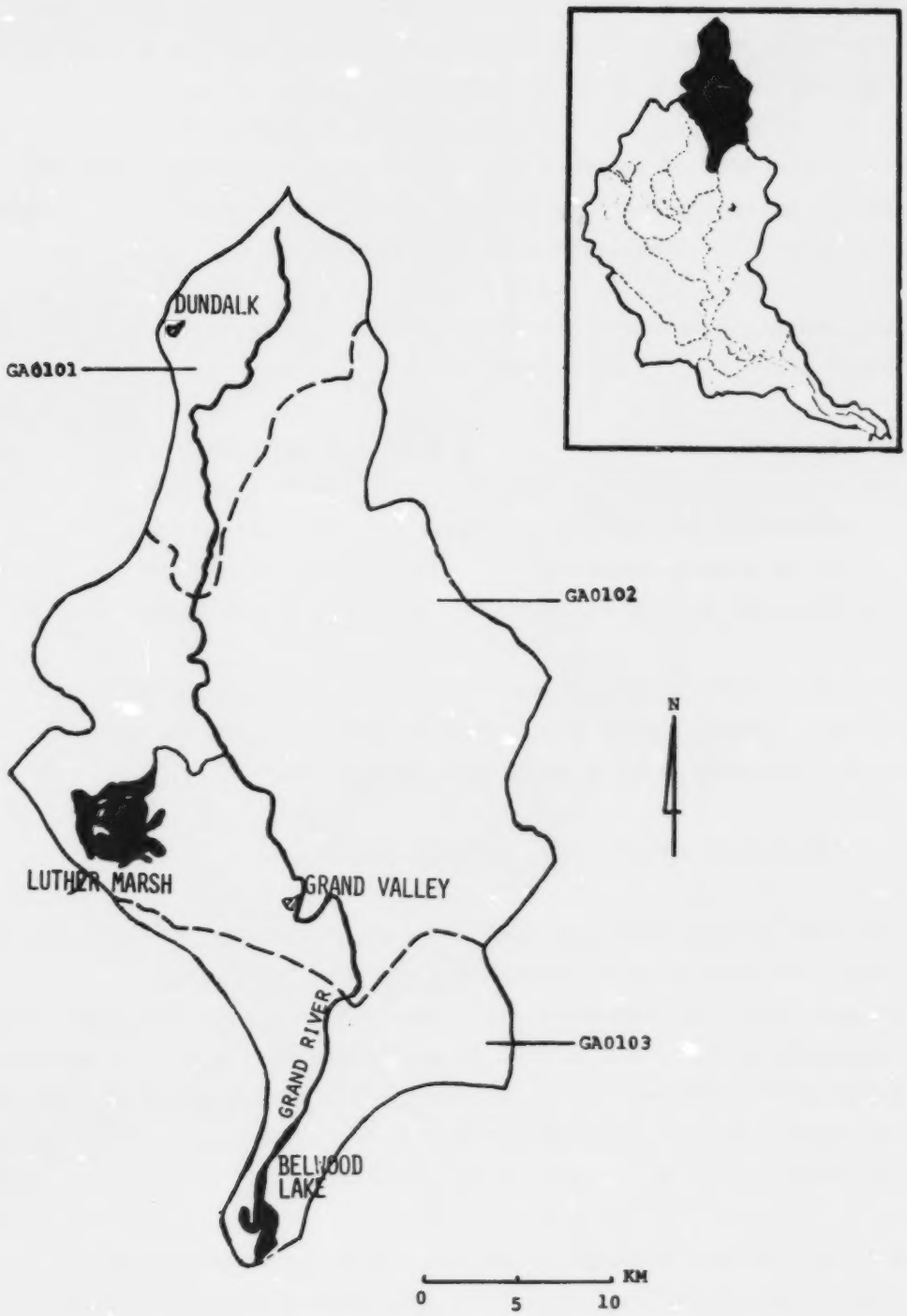


Figure 18. Upper Grand River.

till beneath it, is to form a water-soaked layer that is slow to dry out in the spring, thus preventing early cultivation of the land. The Huron series which is the main soil type in the area is loam in texture containing 20.0% to 27.0% clay.

Less than half of the area is used for crop production, with the main crops being small grains and hay. The number of animal units in the area is small (about 0.3 animal units/ha).

The ranges of measured unit area loads in the upper Grand River basin are:

Suspended solids	25.0 - 60.0 kg/ha/year
Total phosphorus	0.2 kg/ha/year
Filtered reactive phosphorus	0.1 kg/ha/year
Total Kjeldahl nitrogen	2.4 - 4.6 kg/ha/year
Filtered nitrite and nitrate	2.3 - 2.7 kg/ha/year

The above unit area loads are low which is in part due to slow surface runoff in this knob and hill landscape. The main reason however appears to be limited agricultural activities.

6.2 CANAGAGIGUE CREEK ABOVE FLORDALE

The area of this sub-basin (GA0106) is approximately 1860 ha and it forms the upper part of the Canagagigue Creek watershed (Figure 19). The surface deposit consists mainly of clay till. The topography of the area is flat to gently undulating with a slight slope towards the outlet in the south. The area lies mainly within the Stratford till plain physiographic unit. The main soil type is the Huron series which is loamy in texture.

Most of the land drainage is through natural runoff, however, a small area is tile drained. There are about 19.0 km of municipal drains, ditches and streams in the watershed (Frank and Ripley, 1977). Most of the stream banks in the watershed (approximately

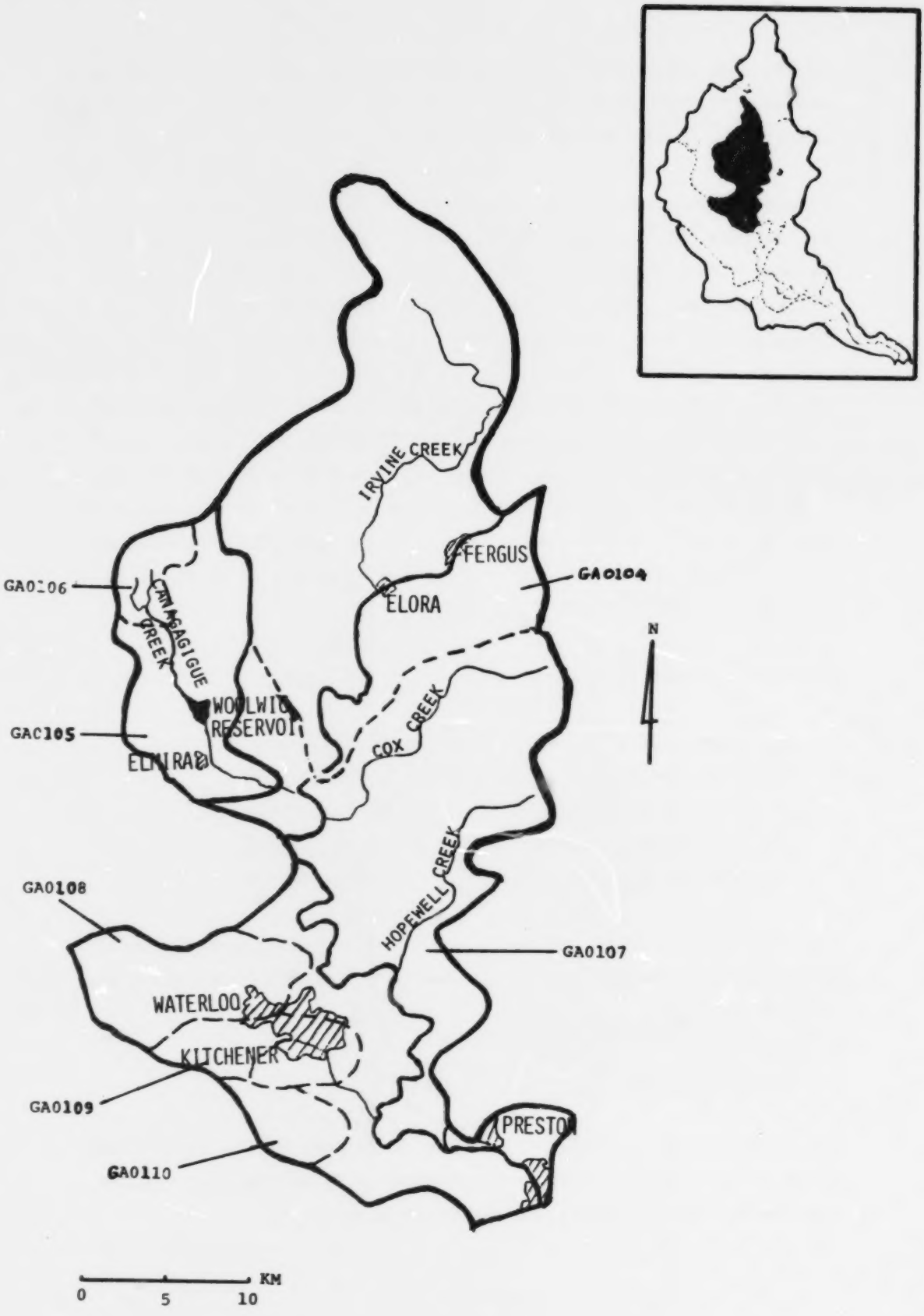


Figure 19. Canagagigue Creek and Middle Grand River.

62.0%) show some evidence of erosion which is due mainly to the absence of stabilizing vegetative cover on approximately 30.0% of these banks (Knapp and Mildner, 1978).

Almost all the land in the watershed (98.0%) is devoted to agricultural production. The agricultural activities include mixed farming with predominantly dairy farming and cropping of corn, small grains and hay. There are few hectares devoted to cash crop production as most crops are grown for livestock feed.

All crop lands within this watershed are usually ploughed in October followed by tillage operations in May. Most of the farmers apply manure to agricultural land. Generally the manure is applied two times a year in April-May and July-November. Most of the manure is handled in solid form after being stored in open piles unprotected from rain. Fertilizer is applied for pre-planting or at planting time in most agricultural land.

The measured unit area loads are:

Suspended solids	490.7 kg/ha/year
Total phosphorus	0.8 kg/ha/year
Filtered reactive phosphorus	0.3 kg/ha/year
Total Kjeldahl nitrogen	4.5 kg/ha/year
Filtered nitrite and nitrate	16.7 kg/ha/year

The elevated levels of all pollutant loads in this sub-basin reflect intensive agricultural activities and to a lesser degree stream bank erosion.

6.3 CONESTOGO RIVER

The Conestogo River drains the northwestern part of the Grand River basin. The watershed area is approximately 77,000 ha and includes sub-basins GA0601, GA0602 and GA0603 (Figure 20).

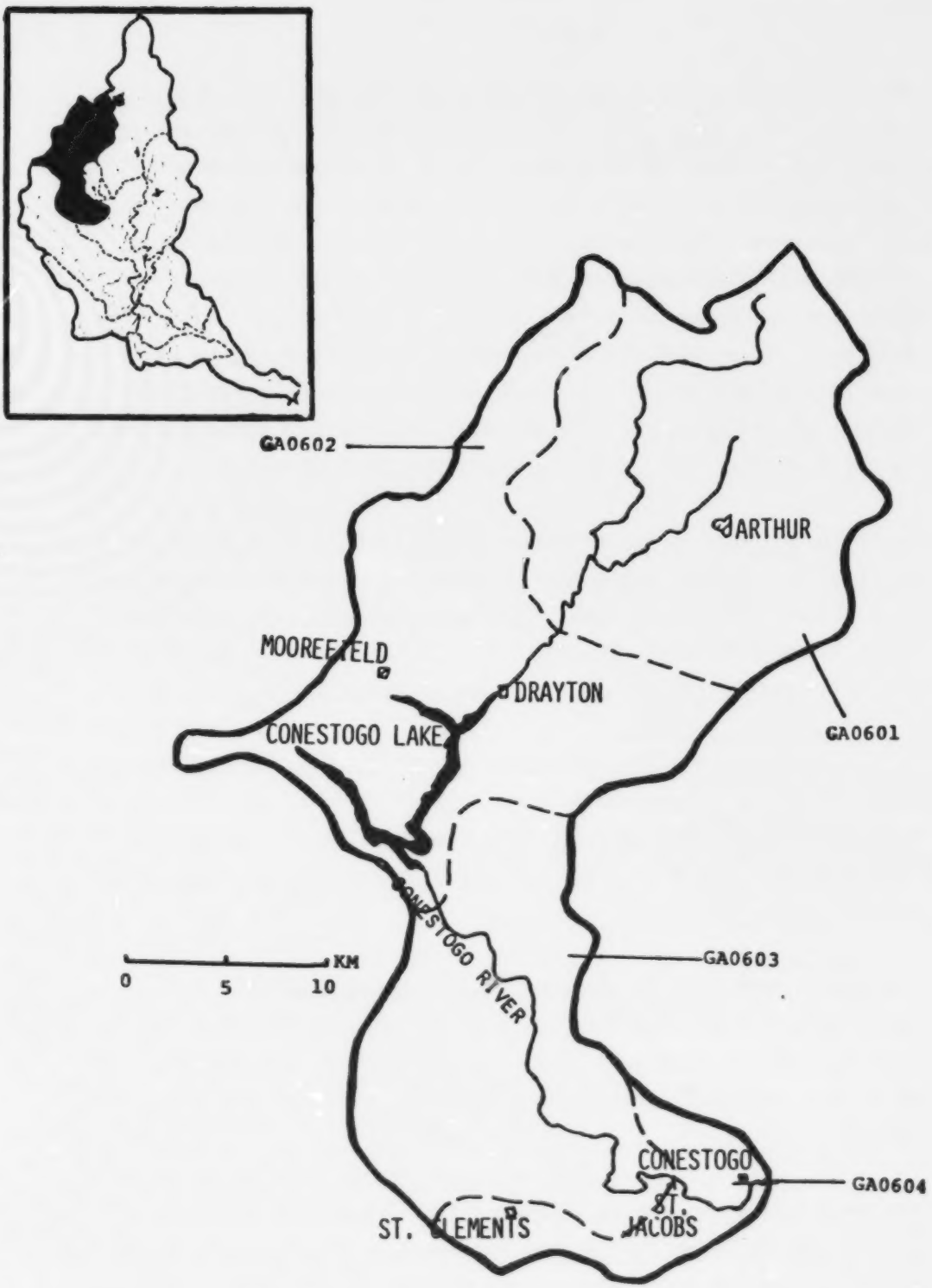


Figure 20. Conestogo River.

The surface deposits in the watershed consist mainly of clay till and silty clay till. The silt and clay contents vary within certain limits and so does the stoniness, but it is seldom a stoney till. Sand or gravel is often present in the valleys near the outlet of the watershed. The upper part of the watershed lies within the Dundalk till plain physiographic unit, whereas most of the remaining area lies within the Stratford till plain physiographic unit. The main soil series within the watershed are the Huron series which may be either silty loam or clay loam, depending on the presence or absence of the surficial silt deposit. Other important soils are Perth, Brookston, Harriston, Listowel and Parkhill series.

In the upper part of the watershed (sub-basin GA0601), approximately 61.0% of the area is designated as farm land which is being utilized as follows: 68.7% crop land, 12.4% pasture, 6.5% wood land and 12.4% unimproved land. The main crops in this part of the watershed are small grains and hay.

In the middle part of the watershed (sub-basin GA0602) most of the area (92.0%) is designated as farm land which is being utilized as crop land (70.0%), pasture (10.0%), wood land (5.7%) and unimproved land (14.3%). The main crops are small grains (40.7%), hay (35.1%) and row crops (24.2%).

The whole lower part of the watershed (sub-basin GA0603) is designated as farm land which is utilized as crop land (75.6%), pasture (10.6%), wood land (7.0%) and unimproved land (6.8%). The main crops are small grains (40.2%), hay (33.3%) and row crops (26.5%).

The amount of animal units increases from 0.3 animal unit per hectare in the upper part of the watershed to 0.6 in the middle part and to 1.0 in the lower part of the watershed. The field survey conducted in 1979 indicates that there are relatively large number of livestock operations adjacent to streams within this watershed (Table 9).

The areas and measured unit area loads (kg/ha/year) in the three sub-basins within the Conestogo River watershed are:

	Sub-basin GA0601	Sub-basin GA0602	Sub-basin GA0603
Area, ha	27707	28829	21000
Suspended solids	723.9	-	416.1
Total phosphorus	0.9	0.3	0.8
Filtered reactive phosphorus	0.2	0.2	0.3
Total Kjeldahl nitrogen	3.6	3.5	4.8
Filtered nitrite and nitrate	4.6	8.4	13.7

Elevated unit area loads of suspended solids in the upper part of the basin may be due to the widespread occurrence of fine textured soils which are imperfectly or poorly drained.

Due to the presence of the Conestogo Lake, the unit area loads computed for sub-basin GA0602 may not be representative of the loads contributed by rural non-point sources within the sub-basin.

Lower unit area loads of suspended solids in the lower part of the watershed, despite more intensive agricultural activities, may reflect the dominance of well drained soils of medium texture (sand and gravel). Increased unit area loads of nitrogen compounds reflect increased intensity of livestock operations.

6.4 NITH RIVER

The total area of the watershed is approximately 104,000 ha and includes sub-basins GA0201, GA0202, GA0203, GA0204, GA0205, GA0206, GA0207, GA0208 and GA0209 (Figure 21). Four types of land forms of glacial origins can be recognized. These are clay till plain, end moraine, kame and outwash, and spillway channels (Figure 5). These deposits largely determine the types of soils within the watershed. The till plain has a relief which ranges from undulating to rolling. The end moraine at Milverton is a hummocky ridge which is characterized by a rougher relief than the till plain. The kame and

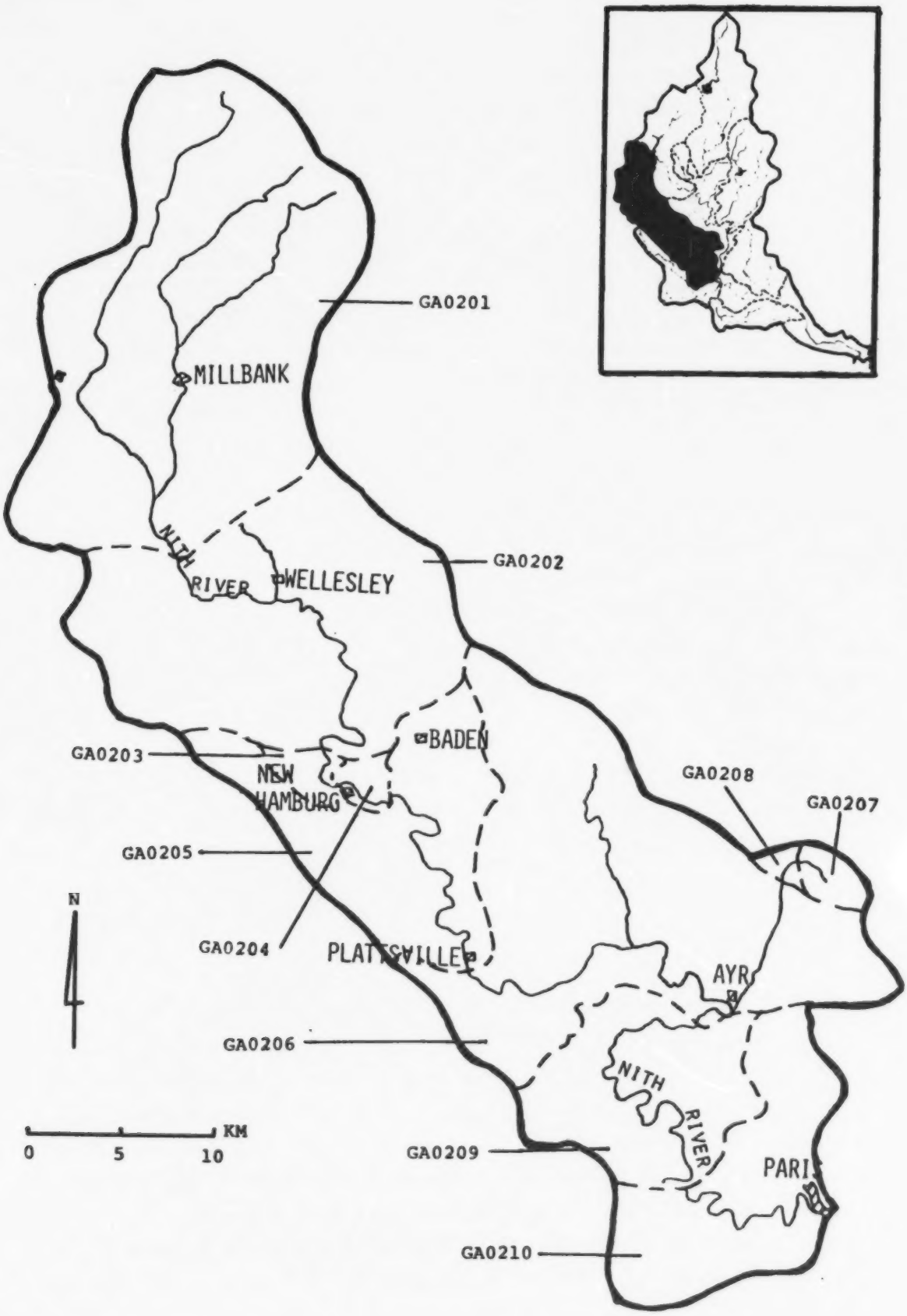


Figure 21. Nith River.

outwash are ranges of very hummocky hills composed of stratified sand and gravel. Broad channels of spillways were deposited by melt water from the glaciers. The main streams now flow in these channels but carry much less water. The most important soil series in the watershed include Huron, Perth; Brookston, Guelph, London, Dumfries, Fox and Waterloo. Soils in the till plan (sub-basin GA0201) are mainly imperfectly or poorly drained whereas the soils in the rest of the watershed are mainly well drained.

Erosion has been speeded up during the period of agricultural settlement. This is partly due to the removal of trees, partly to the change in the soil under cultivtion and partly to the straightening of stream channels and digging of ditches. This may increase the volume and rate of surface runoff with increased flood hazard downstream. Rapid headwater erosion is still underway which causes serious gullying and cave-ins.

In the upper part of the watershed (sub-basins GA0201, GA0202 and GA0205), approximately 84.0% of the area is designated as farm land which is being utilized as crop land (77.0%), pasture (7.0%), wood land (6.7%) and unimproved land (9.3%). The main crops are small grains (35.3%), row crops (32.4%) and hay (32.3%).

In the lower part of the watershed (sub-basins GA0206 and GA0209), only 66.7% of the land is designated as farm land which is divided among crop land (75.1%), pasture (8.7%), wood land (7.3%) and unimproved land (8.9%). The major crops are row crops (55.6%), small grains (24.5%) and hay (19.9%).

The intensity of livestock operations decreases from 0.6 animal units per hectare in the upper part of the watershed to 0.3 in the lower part of the watershed. A large number of livestock operations are located close to the streams (Table 9).

The measured unit area loads (kg/ha/year) in the watershed are:

	Sub-basin GA0201	Sub-basin GA0206, GA0202, GA0205 and GA0209
Area, ha	32363	71637
Suspended solids	314.7	862.7
Total phosphorus	1.3	1.2
Filtered reactive phosphorus	0.4	0.2
Total Kjeldahl nitrogen	4.7	5.3
Filtered nitrite and nitrate	12.8	8.8

The above table indicates that the unit area loads of suspended solids from the lower part of the watershed is approximately three times as much as from the upper part of the watershed. This occurs despite the fact that the natural conditions are more conducive to erosion in the upper part of the watershed. Intensive land use and some poor agricultural practices may be the reason behind this inconsistency. Row crops are more prevalent in the lower part of the watershed. Whereas, small grains and hay are predominant in the upper part of the watershed. In addition, while the flood plain in the upper part of the watershed is occupied by woods it is being used for small grains and row crop production as well as pasture in the lower part of the watershed (Table 11).

The unit area loads of filtered reactive phosphorus and filtered nitrite and nitrate are slightly higher in the upper part of the watershed reflecting more intensive livestock operations.

6.5 SPEED RIVER

The total area of this watershed is approximately 63,000 ha and it contains sub-Basins GA0401, GA0402, GA0403, GA0404, GA0406, GA0407 and GA405 (Figure 22). The watershed exhibits a general decrease in elevation from east to west, due to the dip in the underlying bedrock. This fact has controlled the direction of flows of the main streams in the watershed - the Speed River and its main tributary, the Eramosa River. On the basis of land forms, the Speed River watershed can be divided into the following landscape types:

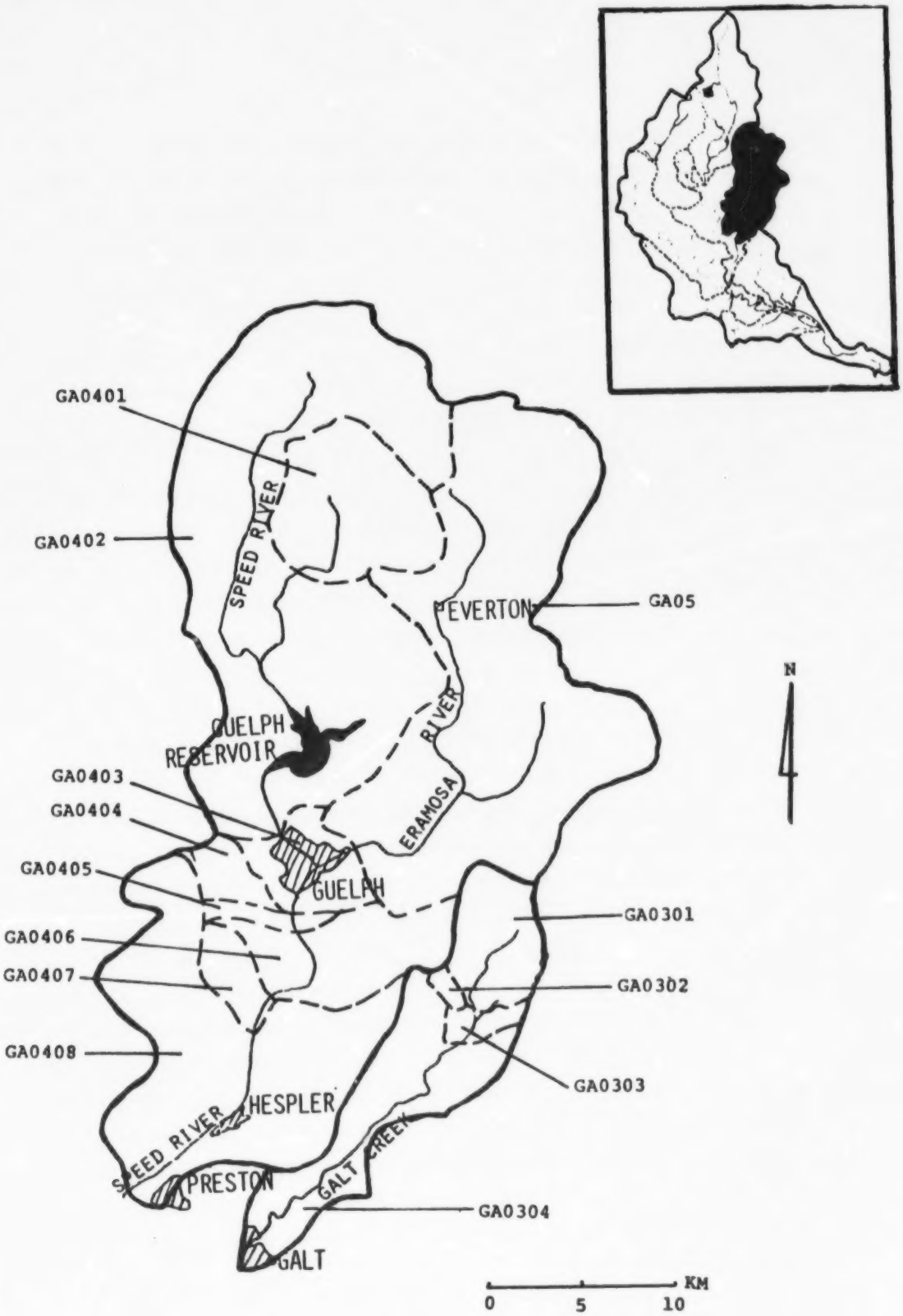


Figure 22. Speed River and Galt Creek.

1) The Hillsburgh sandhills forms the northeastern boundary of the watershed. This area is a kame moraine consisting mostly of fine sandy hills and very little flat land. The soils on the Hillsburgh sand hills are of fine sandy loam type which are quite well suited for potato production

2) The Guelph drumlin field occupies most of the watershed and is characterized by a large number of drumlins of the broad oval type with rather gentle slopes. The drumlins often merge indistinctly into each other so that it is difficult to pick out the individual hills. The till forming the drumlins is loamy and calcareous giving rise to good agricultural soils mainly of the Guelph series. The soils are well drained both internally and externally but retain adequate amount of moisture for the needs of agricultural crops. Erosion hazard is great on the steep slopes.

3) The Paris moraine, which forms the south watershed boundary, is an irregular knobby ridge composed of light textured stony till. The moraine has the roughest land found anywhere on the watershed. The slopes are steep and irregular and interspersed with numerous swampy depressions. The soils are very coarse and stony mainly of the Dumfries series.

4) Outwash plains occupy the area between the Paris moraine and the Guelph drumlin field and the Speed River. The topography of the plains is rolling to flat. The materials forming the plains are mainly stratified gravel in the area between the Paris moraine and the Speed River and stratified sands in the area between the Guelph drumlin field and the Speed River. The main soil types are the Waterloo and Fox series which have good internal drainage and the Granby series which have imperfect to poor internal drainage.

5) The Speed spillways which were carved out by glacial melt water, are presently occupied by the Speed River and the Eramosa River. Swamps and forests cover most of the spillways and they constitute a very effective natural buffer zone.

In the area drained by the main stem of the Speed River (sub-basins GA001, GA0402, GA0404, GA0406, GA0407), approximately 79.0% of the land is designated as farm land. This farm land is divided amcng crop land (68.5%), pasture (8.4%), wood land (8.8%) and unimproved land (14.3%). The major crops are row crops (41.1%), small grains (29.5%) and hay (29.4%).

In the Eramosa River watershed (sub-basin GA05), only 45.2% of the land is designated as farm land which is being utilized as crop land (55.6%), pasture (13.2%), wood land (12.3%) and unimproved land (18.9%). The major crops are hay (43.5%), small grains (34.6%) and row crops (21.9%).

The intensity of livestock operations decreases from 0.4 animal units per hectare in the upper part of the watershed (sub-basin GA0401) to 0.2 animal units per hectare in the lower part of the watershed (sub-basin GA0406) and the Eramosa River watershed (sub-basin GA05).

The areas and measured unit area loads (kg/ha/year) are:

	Speed River Sub-basins GA0401 and GA0402	Eramosa River Sub-basin GA05
Area, ha	36495	26505
Suspended solids	50.7	45.9
Total phosphorus	0.1	0.2
Filtered reactive phosphorus	-	-
Total kjeldahl nitrogen	2.0	-
Filtered nitrite and nitrate	3.6	-

- Estimates not available

The unit area loads of suspended solids produced by the watershed are low. This is not surprising because most of the soils in the watershed are loam to sandy loam with good drainage. The only area where soils are prone to erosion is the Paris Moraine. However, most of this area is not cultivated. Another favourable condition which results in low suspended solids per unit area loads is the presence of green belts in the floodplain which act as an excellent natural buffer strip.

6.6 MIDDLE GRAND RIVER

This area of approximately 75,000 ha contains sub-basins GA0104 and GA0107 (Figure 19). Most of the area is part of the Guelph drumlin field physiographic unit and the remaining small area in the north is part of the Stratford till plain physiographic unit. The surface area is made up mainly of till and stratified sand and gravel. The most prominant soil series are the Guelph, Waterloo and Fox series which have goon internal drainage.

In the upper part of the watershed (sub-basin GA0104), most of the area is designated as farm land (74.7%) which is being utilized as crop land (74.9%), pasture (9.4%), wood land (5.0%). The remaining area (10.7%) is unimproved land. The major crops are small grains (37.3%), row crops (34.3%) and hay (28.4%).

In the lower part of the watershed (sub-basin GA0107), approximately 66% of the area is designated as farm land which is being used as crop land (62.5%), pasture (5.4%) and wood land (8.5%). The remaining 23.6% is unimproved land. The major crops are row crops (47.7%), small grains (29.6%) and hay (22.7%).

The intensity of livestock operations is about the same in both sub-basins and it is equal to 0.5 animal units per hectare.

The areas and measured unit area loads (kg/ha/year) of the two sub-basins are:

	Sub-basins GA0104	Sub-basin GA0107
Area, ha	36752	38276
Suspended solids	459.9	971.9
Total phosphorus	0.6	0.8
Filtered reactive phosphorus	0.03	0.1
Total kjeldahl nitrogen	1.9	2.1
Filtered nitrite and nitrate	9.1	9.9

The elevated levels of suspended solids and total phosphorus loads in both sub-basins reflect high agricultural acitivities (large areas in row crops), intensive stream bank erosion which is aggravated by cattle access to stream channels in many locations and flood plain cropping in part of sub-basin GA0107.

6.7 WHITEMAN CREEK

This area of approximately 38000 ha includes sub-basin GB0501 (Figure 23). The surface area is made up of undrumlinized till plain, till moraine and sand plains. The watershed includes part of the Waterloo Hill, Horshoe Moraine, Norfolk Sand Plain and Oxford Till Plain physiographic units. Major soils are the Perth, Huron, Fox and Burford series; minor soils are the Brookston and Guelph series.

Soil problems in this sub-basin are those associated with fertility, drainage and irrigation because more than one-third of the watershed soils are either imperfectly drained or poorly drained. Considerable tiling and open ditching have been carried out.

The watershed is characterized by low relief with 27% of the land classified as level and 66% as gently sloping. Only 6% of the land is rolling and a mere 1% is steep. As a result of the gentle topography the watershed has a low erosion potential and a high agricultural production capability.

About 79% of this watershed is designated as farm land which is being utilized as crop land (76.1%), pasture (5.2%) and wood land (9.4%). About 9.3% of the farm land is unimproved land. The major crops are row crops (53.6%), small grains (30.3%) and hay 16.1%). There are approximately 0.3 animal units per hectare in the watershed.

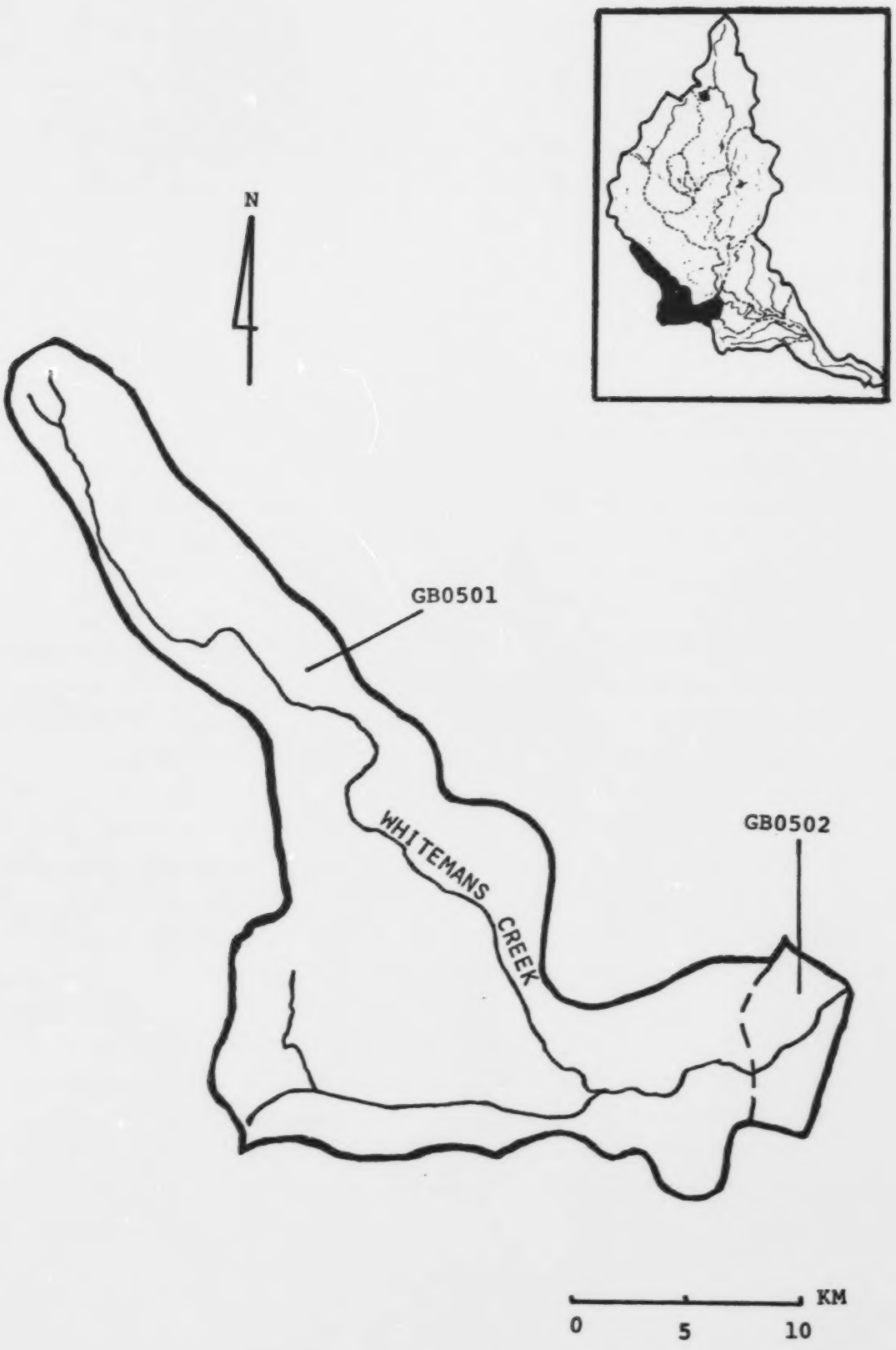


Figure 23. Whitemans Creek.

The area and measured unit area loads (kg/ha/year) of this watershed are:

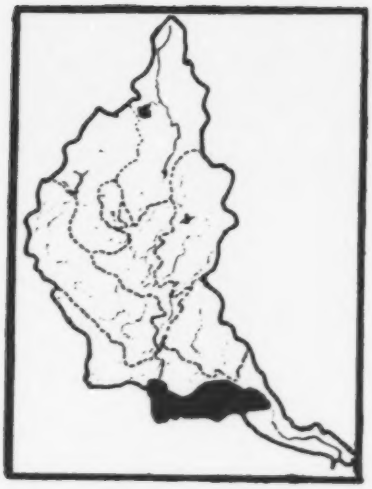
Area, ha	38115
Suspended solids	167.9
Total phosphorus	0.4
Filtered reactive phosphorus	0.1
Total kjeldahl nitrogen	3.2
Filtered nitrite and nitrate	11.9

The low unit area loads of suspended solids and total phosphorus indicate that erosion is not a particularly serious problem in this sub-basin. Medium unit area loads of total Kjeldahl nitrogen and filtered nitrite and nitrate are related to crop fertilization.

6.8 MCKENZIE CREEK

The area of this watershed (sub-basin GB0201) is approximately 20,000 ha (Figure 24). The upper part of the watershed is occupied by the Norfolk sand plain physiographic unit whereas the lower part is occupied by the Haldimand clay plain physiographic unit. The main soil types are the Fox, Brookston, Berrien and Haldimand series. Approximately one-third of the watershed soils are imperfectly drained or poorly drained. The watershed is characterized by low relief ranging from gently sloping to flat.

About 87% of the watershed is designated as farm land which is made of crop land (74.1%), pasture (3.1%), wood land (7.5%) and unimproved land (15.3%). The major crops are row crops (51.1%), small grains (35.5%) and hay (13.4%). Tobacco constitutes 22% of the row crops produced in the watershed and is grown mainly on the Fox series soils which are composed of sand materials. There are only a few livestock operations in the watershed (0.14 animal units/ha).



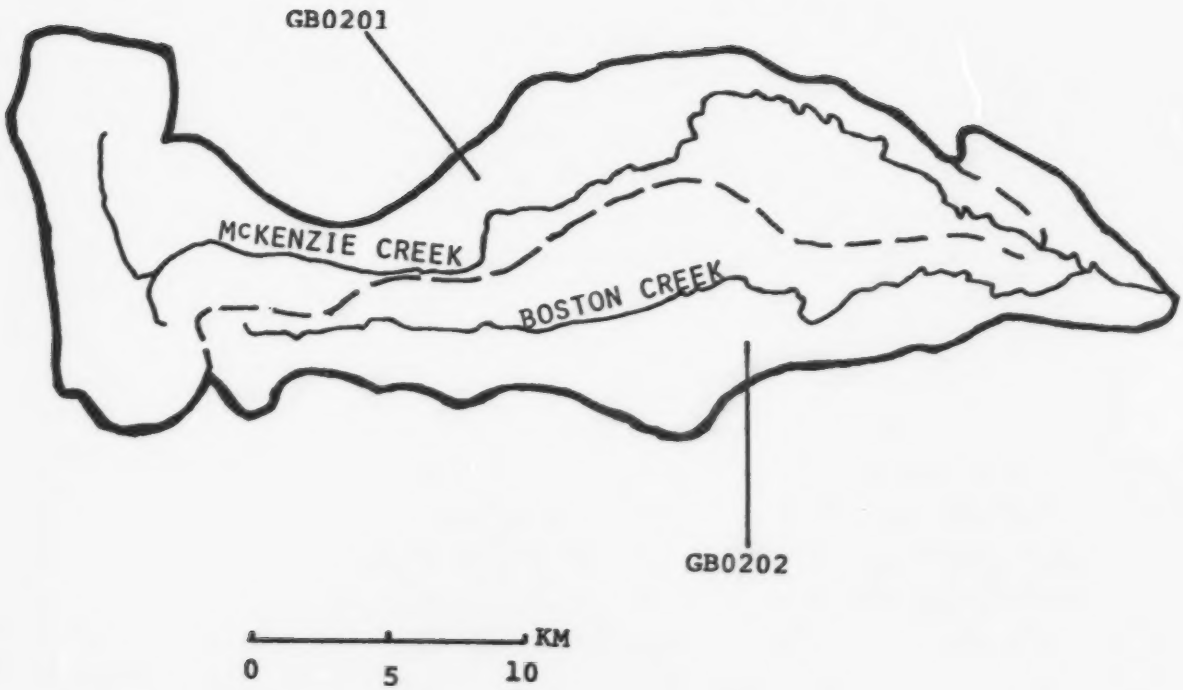


Figure 24. McKenzie Creek and Boston Creek.

The area and measured unit area loads (kg/ha/year) of this watershed are:

Area, ha	20297
Suspended solids	207.3
Total phosphorus	0.4
Filtered reactive phosphorus	0.1
Total kjeldahl nitrogen	2.4
Filtered nitrite and nitrate	5.1

The low level of pollutant loads is indicative of little erosion which is generally due to favourable land forms (near level land) and few livestock operations. Some wind erosion occurs on the tobacco sandy soils. More windbreaks of tree fence-rows would reduce wind erosion and plant damage.

6.9 SUMMARY

Table 12 gives a summary of the findings on unit area pollutant loads as affected by land forms (topography, stream bank condition and natural buffer strip), land use (row crop as percent of basin area, animal units per ha and flood plain cropping) and agricultural practices (cattle access to streams and conventional tillage). The future potential for soil erosion is also indicated in the table.

In the summary, a scoring system (Table 13) was used to indicate the levels of pollutant loadings and the relative significance of various causes. This scoring system is subjective. Low scores of 0 or 1 were assigned to small loads or insignificant causes whereas a high score of 4 was assigned to large loads or significant causes.

Pollution potentials were rated for the sub-basins based on soil characteristics and topography. These potentials can be described as natural pollution potentials as they are primarily related to the natural land form. Column 20 in Table 12 shows that the natural pollution potentials are high in the upper Grand River, Canagagiue Creek, upper Conestogo River, and upper Nith River sub-basins, owing to the presence of fine-textured soils. On the other hand,

Table 12. Summary of Findings on Unit Area Pollutant Loads as Affected by Land Forms, Land Use and Agricultural Practices

Sub-basin	Area ha	Measured Unit Area Pollutant Loads: Suspended Solids	Total Phosphorus	Filtered Reactive Phosphorus	Total Kjeldahl Nitrogen	Filtered Nitrite & Nitrate	Land Forms: Potential for Soil Erosion	Topography	Sum of Columns 8 and 9	Stream Bank Condition	Natural Buffer Strip	Low Proportion of Sub-basin Area	Land Use: Annual Units/ha	Flood Plain Cropping	Agricultural Practices: Cattle Access to Streams	Conventional Tillage	Sum of Columns 11 to 18	Weighted Sum of Columns 10 and 19	Pollution Potential
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21
Upper Grand R. GA0101 & GA0102	68898	1	1	1	2	1	4	2	6	2	1	1	1	1	(1)	(4)	12	18	Medium
GA0103	13400	1	1	2	4	1	4	2	6	1	1	2	1	1	(1)	(4)	13	19	Medium
Middle Grand R. GA0104	36752	3	3	1	1	2	3	1	4 •	2	1	2	3	1	1	(4)	10 •	14 •	Medium
GA0107	30376	4	5	2	2	2	3	1	4 •	2	1	2	3	1	1	(4)	10 •	15 •	Medium
Lower Grand R. GA0106	46399	(1)	2	1	(1)	1	1	1	1 •	(1)	(1)	1	2	2	(1)	(4)	13	14 •	Medium
Tensaw-Bon Co. GA0105 & GA0106	10761	3	3	4	4	4	4	2	6	4	3	2	4	1	1	(4)	17 •	23 •	High
Conasauga R. GA401	37707	4	4	3	3	1	4	1	5	4	1	1	1	1	4	(4)	16	22	High
GA430	29829	5	5	4	3	3	3	2	5	4	1	1	1	1	4	(4)	22	27	Very High
GA503	21500	3	3	4	4	3	3	2	5	4	1	1	1	1	4	(4)	24	29	Very High
Speed R. GA402	5705	1	1	1	2	1	2	1	3	1	1	1	3	1	1	(4)	12 •	17 •	Medium
GA3430	22540	1	1	2	2	2	3	2	5	1	1	1	2	1	1	(4)	13 •	18 •	Medium
GA5408	13682	1	1	2	2	2	2	1	3	1	1	2	2	1	1	(4)	11 •	15 •	Medium
Ecunnora R. GA05	26505	1	1	2	2	2	1	4	5	1	1	1	1	1	1	(4)	9 •	14 •	Low
Abercrombie Cr. GA0301 & GA0304	9261	1	1	1	1	1	2	1	2 •	1	1	1	1	1	(1)	(4)	10	12 •	Low
Satilla River GA0201	32363	2	4	4	4	3	4	2	6	4	4	2	3	1	4	(4)	22	28	Very High
GA0202	21900	4	4	3	4	2	3	2	5	3	4	3	3	2	2	(4)	21	26	Very High
GA0206-GA0210	57469	4	4	3	4	2	3	1	4	3	2	3	3	4	2	(4)	21	25	High
Ogeechee R. GA0501	38115	1	2	2	3	3	3	1	4	3	(1)	4	2	(1)	1	(4)	13 •	17 •	Medium
Mcintosh Co. GA0201	20297	2	2	2	2	2	3	1	3	2	2	2	1	1	1	(4)	9 •	12 •	Low

( ) Estimated
? Data unavailable

Table 12 (Cont'd)

Upper Grand River (sub-basins GA0101 and GA0102)

- Low loadings due to little agricultural activities, stable stream banks and the presence of wet land
- Susceptible to erosion due to fine soil texture

Upper Grand River (sub-basin GA0103)

- Low loadings (except TKN) due to little cropping activities, stable stream banks and good buffer strips
- High loadings of TKN due to livestock operations
- Susceptible to erosion due to fine soil texture

Middle Grand River (sub-basin GA0104)

- High loadings of SS and TP probably due to fast hydrologic response in Irvine Creek and its poor stream bank condition

Middle Grand River (sub-basin GA0107)

- High loadings of SS and TP probably due to intensive row crop cultivation and livestock operations
- Stream bank erosion along Cox Creek
- Cattle access to stream channels and flood plain cropping in the Hopewell Creek watershed
- Susceptible to erosion due to fine soil texture

Lower Grand River (sub-basin GB0102)

- Low loadings due to little agricultural acitivites
- Non-susceptible to erosion due to well-drained soils and flat topography

Canagegigue Creek (sub-basins GA0105 and GA0106)

- High loadings due to intensive livestock operations, poor buffer strips and stream bank erosion
- Susceptible to erosion due to fine soil texture

Conestogo River (sub-basin GA0601)

- High loadings (except FN) due to stream bank erosion and cattle access to stream channels
- Susceptible to erosion due to fine soil texture

Conestogo River (sub-basin GA0602)

- Expected high loadings of SS due to stream bank erosion, poor buffer strips and cattle access to streams
- High loadings of FP and TKN due to intensive livestock operations and cattle access to streams
- Susceptible to erosion due to fine soil texture

Conestogo River (sub-basin GA0603)

- High loadings due to intensive row crop cultivation and livestock operations, stream bank erosion, poor buffer strips and cattle access to streams
- Susceptible to erosion due to fine soil texture

Speed River (sub-basin GA0401)

- Low loadings due to little cropping activities, stable stream banks and good natural buffer strips
- Susceptible to erosion due to steep topography

Speed River (sub-basin GA0402)

- Low loadings due to stable stream bank and good natural buffer strips
- Susceptible to erosion due to steep topography

Speed River (sub-basin GA0408)

- Low loadings due to little agricultural activities, stable stream banks and good natural buffer strips
- Susceptible to erosion due to steep topography

Eramosa River (sub-basin GA05)

- Low loadings due to little agricultural activities and stable stream banks
- Susceptible to erosion due to steep topography

Aberfoyle Creek (sub-basins GA0301 and GA0304)

- Low loadings due to little agricultural activities, stable stream banks and good natural buffer strips

Nith River (sub-basin GA0201)

- High loadings (except SS) due to stream bank erosion, poor natural buffer strip, intensive livestock operations and cattle access to streams
- Susceptible to erosion due to fine soil texture

Nith River (sub-basin GA0202)

- High loadings (except FN) due to intensive row crop cultivation and livestock operations, stream bank erosion, poor natural buffer strips and cropping in the flood plain.
- Susceptible to erosion due to steep topography

Nith River (sub-basins GA0205, GA0206, GA0209 and GA0210)

- High loadings (except FN) due to intensive row crop cultivation and livestock operations, stream bank erosion and flood plain cropping
- Susceptible to erosion due to steep topography

Whiteman Creek (sub-basin GB0501)

- High loadings of TKN and FN due to intensive row crop cultivation
- Low loadings of SS, TP and FRP due to stable stream banks, good natural buffer strips and flat topography

McKenzie Creek (sub-basin GB0201)

- Low loadings due to little agricultural acitivities
- Non-susceptible to erosion due to well-drained soil and flat topography

SS:suspended solids TP:total phosphorus FRP:filtered reactive phosphorus
TKN:total Kjeldahl nitrogen FN:filtered nitrite and nitrate

Table 13. Weighting Scores for Various Parameters Used in the Summary Matrix

Parameter	Range	Scores
Suspended solids, kg/ha/year	200	1
	200-400	2
	400-600	3
	600	4
Total phosphorus, kg/ha/year	0.3	1
	0.3-0.6	2
	0.6-0.9	3
	0.9	4
Filtered reactive phosphorus kg/ha/year	0.07	1
	0.07-0.14	2
	0.14-0.21	3
	0.21	4
Total Kjeldahl nitrogen kg/ha/year	2.0	1
	2.0-3.0	2
	3.0-4.0	3
	4.0	4
Filtered nitrite and nitrate kg/ha/year	5.0	1
	5.0-10.0	2
	10.0-15.0	3
	15.0	4
Potential for soil erosion	Low	1
	Moderate	2
	High	3
	Very high	4
Topography	Level	1
	Gently sloping	2
	Rolling	3
	Hilly	4
Stream bank conditions	None or occasional problem	1
	Minor problem	2
	Moderate problem	3
	Major problem	4
Natural buffer strips	Adequate in all locations	1
	Adequate in most locations	2
	Adequate in some locations	3
	Inadequate	4
Row crops, % of sub-basin area	10.0	1
	10.0-20.0	2
	20.0-30.0	3
	30.0	4
Livestock operations, animal units/ha	0.3	1
	0.3-0.5	2
	0.5-0.8	3
	0.8	4
Flood plain cropping	None or occasional	1
	Minor problem	2
	Moderate problem	3
	Major problem	4
Cattle access to streams	None or occasional	1
	Minor problem	2
	Moderate problem	3
	Major problem	4
Conventional tillage	No tillage	1
	Minimum tillage	2
	Conservation tillage	3
	Conventional tillage	4

potentials are low in the lower Grand River sub-basin, due to the relatively flat topography there, and in the Aberfoyle Creek sub-basin, because of the presence of medium to coarse textured soils.

Stream bank conditions, natural buffer strips, agricultural land use and practices were rated with respect to their combined effect on pollutant loadings. The results, given in Column 21 in Table 12, show that the influence of these four factors are strong in the Canagagigue Creek, middle and lower Conestogo River and the Nith River sub-basins. The intensities of cropping and livestock operations are higher in these sub-basins than the remaining area of the Grand River basin. Flood plain cropping, cattle access to streams, the absence of buffer strips, and stream bank erosion have been identified as the source pollutant loads in some of these sub-basins.

The existing pollution levels were rated according to the loadings of suspended solids, total phosphorus, filtered reactive phosphorus, total kjeldahl nitrogen and filtered nitrite. As shonw in Column 22 in Table 12, the existing pollution levels are high in the Canagagigue Creek sub-basin, the middle Grand River sub-basin below the mouth of Canagagigue Creek, part of the Conestogo River basin and the Nith River basin. In these sub-basins, the natural pollution potentials are either medium or high whereas the streambank conditions, buffer strip, agricultural land use and practices are conducive to high pollutant loadings.

7. EXTRAPOLATION OF RURAL NON-POINT SOURCE POLLUTION LOADS

7.1 RELATIONSHIPS BETWEEN BASIN CHARACTERISTICS AND UNIT AREA LOADS

The relationships between a few land form and land use characteristics in fifteen sub-basins in the Grand River basin and the unit area loads from these sub-basins were investigated through correlation analyses. Results of the analyses are given in Table 14.

The characteristics which were considered in the analyses are: soil clay content, crop land, total corn, row crops, small grains, hay, intensity of livestock operations, pasture, wood land, and estimated phosphorus and nitrogen inputs which resulted from fertilizer application and manure production. These characteristics were chosen based on several agricultural watershed studies conducted during the PLUARG program (Wall et al 1978, Miller and McBride 1977, and Neilson 1978). No data were available to include parameters on agricultural land management practices.

Relatively strong correlations were found between the unit area loads of suspended solids and the percent of land in row crops ($r = 0.89$) and the percent of land in corn ($r = 0.87$). The percent of clay in soil was not found to be significant ($r = -0.09$).

The unit area loads of total phosphorus were found to be correlated with the percent of clay in soil ($r = 0.73$) and with the sum of phosphorus inputs (TPUSED) from fertilizer applied and manure produced ($r = 0.68$). The unit area loads of filtered reactive phosphorus are also correlated with the percent of clay in soil ($r = 0.75$) and with the parameter TPUSED ($r = 0.63$).

The unit area loads of total Kjeldahl nitrogen were found to be correlated with the percent of clay in soil ($r = 0.79$) and the sum of nitrogen inputs (TNUSED) from fertilizer applied and manure produced ($r = 0.68$). However, the unit area loads of filtered nitrite and nitrate were weakly correlated with the percent of clay in soil ($r = 0.06$).

Table 14. Coefficients of Simple Correlation (r) Between Unit Area Loads and Selected Sub-Basin Characteristics

Sub-Basin Characteristics	Suspended Solids kg/ha/year	Total Phosphorus kg/ha/year	Filtered Reactive Phosphorus kg/ha/year	Total Kjeldahl Nitrogen kg/ha/year	Filtered Nitrite and Nitrate kg/ha/year
clay content (% of soil)	0.09	0.73	0.75	0.79	0.06
total corn (% of sub-basin area)	0.87	0.43	0.53	0.54	0.69
row crop (% of sub-basin area)	0.89	0.50	0.44	0.59	0.58
small grains (% of sub-basin area)	-0.01	0.52	0.59	0.64	0.53
hay (% of sub-basin area)	-0.30	0.45	0.52	0.60	0.50
intensity of livestock operations (au/ha)	0.15	0.57	0.56	0.61	0.58
estimated phosphorus inputs (kg/ha/year)	0.27	0.68*	0.63	-	-
estimated nitrogen inputs (kg/ha/year)	0.29	-	-	0.68	0.72
crop land (% of sub-basin area)	0.30	0.55	0.61	0.60	0.61
pasture (% of sub-basin area)	-0.49	0.07	0.22	0.25	-0.04
woodland (% of sub-basin area)	0.08	-0.16	0.01	0.19	0.24

In general, the unit area loads of phosphorus and nitrogen were found to have statistically significant correlations (based on the student-t test at a significance level of 0.05) with crop land, small grains, hay and the intensity of livestock operations. This reflects the fact that these pollutant loads are proportional to the amount of fertilizer applied and the amount of manure produced. Unfortunately, data related to fertilizer usage and manure production were collected only in the 1971 agriculture census. In order to predict the fertilizer usage and manure production in 1976, the following regression equations were developed from the 1971 agricultural census data:

$$FP = 0.29\ (RC) + 0.12\ (SG) + 0.09\ (HAY) \qquad r^2 = 0.66 \qquad (1)$$
$$s.e. = 1.82\ (22.1\%\ \text{of the mean FP})$$

$$MP = 17.45\ (AU) \qquad r^2 = 0.93 \qquad (2)$$
$$s.e. = 0.83\ (13.5\%\ \text{of the mean MP})$$

$$FN = 0.97\ (RC) + 0.11\ (SG) + 0.19\ (HAY) \qquad r^2 = 0.80 \qquad (3)$$
$$s.e. = 4.65\ (22.3\%\ \text{of the mean FN})$$

$$MN = 72.18\ (AU) \qquad r^2 = 0.94 \qquad (4)$$
$$s.e. = 3.20\ (12.6\%\ \text{of the mean MN})$$

where:

FP = phosphorus input from fertilizer application, kg/ha/year,
RC = percent of sub-basin area in row crops,
SG = percent of sub-basin area in small grains,
HAY = percent of sub-basin area in hay,
MP = phosphorus input from manure production kg/ha/year,
AU = animal units per hectare,
FN = nitrogen input from fertilizer application, kg/ha/year,
MN = nitrogen input from manure production, kg/ha/year.

The above equations were used to estimate the total phosphorus and nitrogen utilized in each sub-basin for the year 1976. It was assumed that the total phosphorus input within each sub-basin is the sum of phosphorus inputs from fertilizer application and manure

production. Also, it was assumed that the total nitrogen input within each sub-basin is the sum of nitrogen inputs from fertilizer application and manure production. The agricultural census data of 1976 on row crops, small grains, hay and animal units per hectare were used in these calculations.

7.2 REGRESSION EQUATIONS

An attempt was made to develop regression equations to relate the unit area loads of pollutants and a few important sub-basin characteristics. These characteristics were identified as described in Section 7.1 through correlation analyses.

7.2.1 Suspended Solids

Table 14 shows that only two sub-basin characteristics - the percent of sub-basin area in corn and the percent of sub-basin area in row crops - have relatively strong correlations with the unit area loads of suspended solids. The regression equation developed is as follows:

$$SSUAL = -226 + 40\ (RC) \qquad (5)$$
$$r^2 = 0.79$$
$$s.e. = 174 \text{ kg/ha/year}$$

where SSUAL = unit area load of suspended solids, kg/ha/year,
RC = percent of sub-basin area in row crops.

The standard error of estimate (s.e.) is approximately 40% of the mean unit area load of suspended solids (441 kg/ha/year). A better regression equation (with higher r^2 value and lower s.e.) could not be obtained by including the percent of sub-basin area in corn as an explanatory variable. This is not surprising because corn constituted more than 90 percent of row crops in most sub-basins.

Equation 5 is different from the suspended solids loading equation developed in the PLUARG study (Wall et al, 1978) in that it relates the unit area loads of suspended solids to the intensity of row crop cultivation and not to the clay content in the soil. For the Grand River basin, weak correlation ($r = -0.09$) was found between the unit area loads of suspended solids and the clay content in the soil.

Table 15 gives a comparison of the measured and predicted unit area loads of suspended solids for various sub-basins in the Grand River basin. The differences between predicted and measured unit area loads are less than 200 kg/ha/year for all but one sub-basins. For the upper Speed River (sub-basin GA0401), the predicted unit area load is almost an order of magnitude larger than the measured value. This discrepancy can be attributed to the presence of good natural buffer strips along the upper Speed River.

7.2.2 Total Phosphorus

The regression equation developed for the unit area loads of total phosphorus is as follows:

$$\text{TPUAL} = -0.198 + 0.0335\ (\text{CLAY}) + 0.0102\ (\text{TPUSED}) \qquad (6)$$

$$r^2 = 0.55$$

$$\text{s.e.} = 0.27$$

where TPUAL = unit area load of total phosphorus, kg/ha/year,
CLAY = percent of clay in soild
TPUSED = the sum of phosphorus inputs from fertilizer applied and manure produced, kg/ha/year.

The standard error of estimate (s.e.) is about 45% of the mean measured unit area load (0.59 kg/ha/year). Values for the parameter TPUSED were not available for the year 1976 and had to be generated using Equations 1 and 2 (Section 7.1).

Table 15. Measured and Predicted Unit Area Loads of Suspended Solids

Sub-Basin	Sub-Basin Code	Measured Unit Area Loads kg/ha/year	Predicted Unit Area Loads kg/ha/year
Upper Grand	GA0101, GA0102	57	0
Middle Grand	GA0104	460	489
Middle Grand	GA0107, GA0108, GA0408, GA0604	972	659
Lower Grand	GA0111, GA0210, GB0101, GB0502	1162	1002
Canagagigue	GA0106	491	544
Lower Conestogo	GA0603	416	639
Upper Speed	GA0401	42	319
Eramosa	GA05	46	0
Galt	GA0301	27	0
Upper Nith	GA0201	315	410
Lower Nith	GA0201 to GA0209	863	793

Table 16 shows that the predicted and measured unit area loads of total phosphorus are within the same order of magnitude. This is despite the fact that estimated values for the parameter TPUSED were used to predict unit area loads.

7.2.3 Filtered Reactive Phosphorus

The regression equation developed for the unit area loads of filtered reactive phosphorus is as follows:

$$\text{FRPUAL} = -0.173 + 0.0112\ (\text{CLAY}) + 0.00537\ (\text{TPUSED}) \qquad (7)$$
$$r^2 = 0.62$$
$$\text{s.e.} = 0.08$$

where FRPUAL = unit area load of filtered reactive phosphorus, kg/ha/year,
CLAY = percent of clay in soil,
TPUSED = the sum of phosphorus inputs from fertilizer applied and manure produced, kg/ha/year.

The standard error is approximately 59% of the mean measured unit area load (0.135 kg/ha/year).

Table 17 shows that the predicted unit area loads of filtered reactive phosphorus compare well with the measured values. In most cases, the deviations are less than 0.09 kg/ha/year.

7.2.4 Total Kjeldahl Nitrogen

The regression equation developed for the prediction of the unit area loads of total kjeldahl nitrogen is as follows:

$$\text{TKNUAL} = -0.006 + 0.119\ (\text{CLAY}) + 0.016\ (\text{TNUSED}) \qquad (8)$$
$$r^2 = 0.69$$
$$\text{s.e.} = 0.75$$

Table 16. Measured and Predicted Unit Area Loads of Total Phosphorus

Sub-Basin	Sub-Basin Code	Measured Unit Area Loads kg/ha/year	Predicted Unit Area Loads kg/ha/year
Upper Grand	GA0101, GA0102	0.25	0.55
Middle Grand	GA0104	0.62	0.46
Middle Grand	GA0107, GA0108, GA0408, GA0604	0.76	0.48
Lower Grand	GB0102, GB0202, GB03, GB04	0.59	0.76
Canagagigue	GA0106	0.84	0.89
Upper Conestogo	GA0601	0.92	0.69
Lower Conestogo	GA0603	0.80	1.02
Upper Speed	GA0401	0.08	0.37
Eramosa	GA05	0.16	0.17
Galt	GA0301	0.07	0.04
Upper Nith	GA0201	1.27	0.99
Lower Nith	GA0201 to GA0209	1.19	0.62
Whiteman	GA0501	0.40	0.48
McKenzie	GB0201	0.36	0.53

Table 17. Measured and Predicted Unit Area Loads of Filtered Reactive Phosphorus

Sub-Basin	Sub-Basin Code	Measured Unit Area Loads kg/ha/year	Predicted Unit Area Loads kg/ha/year
Upper Grand	GA0101, GA0102	0.02	0.09
Middle Grand	GA0104	0.04	0.08
Middle Grand	GA0107, GA0108, GA0408, GA0604	0.11	0.09
Lower Grand	GB0102, GB0202, GB03, GB04	0.02	0.18
Canagagigue	GA0106	0.30	0.24
Upper Conestogo	GA0601	0.20	0.14
Lower Conestogo	GA0603	0.26	0.29
Upper Speed	GA0401	0.01	0.04
Galt	GA0301	0.01	0.00
Upper Nith	GA0201	0.44	0.26
Lower Nith	GA0201 to GA0209	0.16	0.14
Whiteman	GA0501	0.10	0.08
McKenzie	GB0201	0.09	0.10

where TKNUAL = unit area load of total Kjeldahl nitrogen, kg/ha/year,
CLAY = per cent of clay in soil,
TNUSED = the sum of nitrogen inputs from fertilizer applied and manure produced, kg/ha/year.

The standard error is approximately 24% of the mean measured unit area load (3.185 kg/ha/year). Values for the parameter TNUSED in Equation 8 were generated using Equations 3 and 4 (Section 7.1) since data were not available for the year 1976.

Table 18 shows that the predicted unit area loads of total kjeldahl nitrogen agree well with the measured loads.

7.2.5 Filtered Nitrite and Nitrate

The regression equation obtained for the unit area loads of filtered nitrite and nitrate is as follows:

$$FNUAL = -1.066 + 0.176\ (TNUSED) \quad (9)$$
$$r^2 = 0.52$$
$$s.e. = 4.23$$

where FNUAL = unit area loads of filtered nitrite annd nitrate, kg/ha/year,
TNUSED = the sum of nitrogen inputs from fertilizer applied and manure produced, kg/ha/year.

The standard error is approximately 40% of the mean measured unit area load (8.722 kg/ha/year). As shown in Table 19 the predicted unit area loads compare well with the measured values except for two cases. For the lower Grand River, the predicted value is les than one half of the measured value. For Canagagigue Creek, the predicted value is almost four times the measured. It is possible that for these two sub-basins, the estimated nitrogen inputs are significantly different from the amounts used.

Table 18. Measured and Predicted Unit Area Loads of Total Kjeldahl Nitrogen

Sub-Basin	Sub-Basin Code	Measured Unit Area Loads kg/ha/year	Predicted Unit Area Loads kg/ha/year
Upper Grand	GA0101, GA0102	2.42	2.84
Middle Grand	GA0104	1.90	2.02
Middle Grand	GA0107, GA0108, GA0408, GA0604	2.11	2.75
Canagagigue	GA0106	4.54	4.47
Upper Conestogo	GA0601	3.61	3.31
Lower Conestogo	GA0603	4.76	5.00
Upper Speed	GA0401	2.03	2.31
Galt	GA0301	1.27	0.90
Upper Nith	GA0201	4.73	4.62
Lower Nith	GA0201 to GA0209	5.33	3.27
Whiteman	GA0501	3.16	2.75
McKenzie	GB0201	2.36	2.85

Table 19. Measured and Predicted Unit Area Loads of Filtered Nitrite and Nitrate

Sub-Basin	Sub-Basin Code	Measured Unit Area Loads kg/ha/year	Predicted Unit Area Loads kg/ha/year
Upper Grand	GA0101, GA0102	2.17	3.91
Middle Grand	GA0104	9.09	8.69
Middle Grand	GA0107, GA0108, GA0408, GA0604	9.92	9.60
Lower Grand	GA0111, GA0210, GB0101, GB0502	20.53	8.71
Canagagigue	GA0106	1.76	6.73
Upper Conestogo	GA0601	16.66	15.07
Lower Conestogo	GA0603	4.61	3.90
Upper Speed	GA0401	13.66	16.91
Galt	GA0301	3.57	7.07
Upper Nith	GA0201	1.57	1.27
Lower Nith	GA0201 to GA0209	12.78	10.09
Whiteman	GA0501	11.86	8.98
McKenzie	GB0201	5.11	6.62

7.2.6 Summary

Five equations have been developed through regression analyses. Each equation relates the unit area load of pollutants (suspended solids, total phosphorus, filtered reactive phosphorus, total kjeldahl nitrogen, filtered nitrite and nitrate) to one or two sub-basin characteristics.

The standard errors associated with the five regression equations developed range from 24% to 59% of the mean measured unit area loads. These errors are considered small in light of the fact that no more than two sub-basin characteristics are employed in each regression equation.

7.3 EXTRAPOLATION OF POLLUTANT LOADS TO THE YEARS 2001 and 2031

The regression equations presented in Section 7.2 were used to extrapolate pollutant loads for various sub-basins within the Grand River watershed to the years 2001 and 2031. Two agricultural land use scenarios were investigated.

The first scenario projects large increases in both row crops and livestock operations (Table 20). The row crop area within the basin is projected to increase from 112,557 ha (16% of the basin area) in 1976 to 190,501 (27% of the basin area) in 2001 and 232,003 (33% of the basin area) in 2031. As for livestock operations the number of animal units in the basin is projected to increase from 242,991 in 1976 to 323,107 in 2001 and 392,777 in 2031. This scenario is a slightly modified version of the scenario developed by M. H. Miller and R. A. McBride (1979). The modifications reflect the views of agricultural representatives in the basin (Mr. D. Graham, Brant County Agricultural Representative; Mr. D. Keyes, Wentworth Country Agricultural Representative; oral communications).

The second scenario (Table 21) considers a land use development which is one half of the increases assumed in the first scenario. This scenario is included for comparison purposes in case the pace

Table 20. Projected Row Crop and Animal Units for the Years 2001 and 2031 Based on Intensive Future Land Use Development

SUB-BASIN	TA	RC 1976	RC 2001	RC 2031	AU 1976	AU 2001	AU 2031
GA0101-0102	68898	2501	5942	10418	18674	20424	20424
GA0103	13400	1737	3706	5974	5514	5514	5514
GA0104	36752	6513	14748	21519	17363	25171	32036
GA0107-0110	50973	7797	9000	9000	16561	29734	40529
GA0111	9617	2242	2789	2789	3324	3354	3023
GB0101-0103	78877	8205	20794	22984	12706	12706	12706
GA0105-0106	10761	1965	3000	3000	8140	13926	18982
GA0601	27707	1429	4207	7328	7626	13017	16567
GA0602	28829	4643	8676	15115	17938	21949	27935
GA0603-0604	26562	6109	11222	13599	26693	27146	35950
GA0401-0402	27853	6309	11370	12816	4279	16118	20514
GA0403-0408	22977	2515	2500	2500	4243	7767	10286
GA05	26505	1310	5044	6449	4486	9092	11571
GA0301-0304	9926	432	1315	1338	1553	2423	3084
GA0201-0210	114617	26835	38897	47063	58705	7934210	1052
GB0501-0502	40754	12858	20186	20186	12611	12849	10029
GB03-04	58878	12256	15767	16273	17856	17856	17856
GB0201	20297	3947	6338	6652	1764	1764	1764
GB0202	23083	2954	5000	7000	2955	2955	2955
TOTAL	696466	112557	190501	232003	242991	323107	392777

TA - sub-basin area in ha
RC - row crop area in ha for the years 1976, 2001 and 2031
AU - annual units for the years 1976, 2001 and 2031 (an animal unit is defined as the number of any kind of livestock that will produce 70-80 kg of nitrogen in manure per year)

Table 21. Projected Row Crops and Animal Units for the Years 2001 and 2031 Based on Modest Future Land Use Development

SUB-BASIN	TA	RC 1976	RC 2001	RC 2031	AU 1976	AU 2001	AU 2031
GA0101-0102	68898	2501	4222	6460	18674	19549	19549
GA0103	13400	1737	3856	5514	5514	5514	5514
GA0104	36752	6513	10631	14016	17363	21267	24700
GA0107-0110	50973	7797	8399	8399	16561	23148	28545
GA0111	9617	2242	2516	2516	3324	3354	3023
GB0101-0103	78877	8205	14500	15595	12706	12706	12706
GA0105-0106	10761	1965	2483	2483	8140	11033	13561
GA0601	27707	1429	2818	4379	7626	10322	12097
GA0602	28829	4643	6660	9879	17938	19944	22937
GA0603-0604	26562	6109	8666	9854	26693	26920	31322
GA0401-0402	27853	6309	8840	9563	4279	10198	12397
GA0403-0408	22977	2515	2515	2515	4243	6005	7265
GA05	26505	1310	3177	3880	4486	6789	8029
GA0301-0304	9926	432	874	885	1553	1988	2319
GA0201-0210	114617	26835	32866	36949	58705	69024	79879
GB0501-0502	40754	12858	16522	16522	12611	12849	10029
GB03-04	58878	12256	14012	14265	17856	17856	17856
GB0201	20297	3947	5143	5300	1764	1764	1764
GB0202	23083	2954	3977	4977	2955	2955	2955
TOTAL	696466	112557	151543	172293	242991	283185	316447

TA - sub-basin area in ha
RC - row crop area in ha for the years 1976, 2001 and 2031
AU - annual units for the years 1976, 2001 and 2031 (an animal unit is defined as the number of any kind of livestock that will produce 70-80 kg of nitrogen in manure per year)

of development will prove to be slower than the trend established in the past fifteen years. This trend constituted the basis on which Miller and McBride developed their projections.

Tables 22, 23, 24, 25 and 26 give the extrapolated unit area loads (kg/ha/year) and the total sub-basin loads (t/year) for both scenarios in terms of suspended solids, total phosphorus, filtered reactive phosphorus, total kjeldahl nitrogen and filtered nitrite and nitrate. Measured values of the above five pollutants in 1976 are also provided for comparison purposes. Because water quality monitoring stations did not always coincide with the outlets of the sub-basins, some missing data for these sub-basin became unavoidable.

Based on Tables 20, 21 and 22, the following observations were made with regard to the extrapolation of suspended solids loads:

1. Measured unit area loads of suspended solids for the year 1976 were less than 500 kg/ha/year in all sub-basins with the exception of the Nith River and the upper Conestogo River. Row crop production was more intensive in the Nith River than other parts of the Grand River basin.

2. For both land use scenarios developed for the year 2001, relatively intensive row crop cultivation (with row crops occupying more than 20% of the sub-basin area) are projected in parts of the main stem of the Grand River (sub-basins GA0103, GA0104 and GA0111), Canagagigue Creek, the middle and lower Conestogo River, the upper Speed River, the Nith River, Whiteman Creek, Big Creek, Fairchild Creek and McKenzie Creek (sub-basin GB0201). Projected unit area loads of suspended solids for these sub-basins are above 500 kg/ha/year and some of the projected values reach as high as 1500 kg/ha/year.

3. Based on projections developed for the two land use scenarios, row crops would occupy in the year 2031 from 24.7% (modest development) to 33.3% (intensive development) of the area of the

Table 22. Extrapolation of Unit Area Loads (UAL, kg/ha/year) and Sub-Basin Loads (SBL, t/year) of Suspended Solids

Sub-basin		SUB-BASIN AREA ha	MEASURED		MODEST DEVELOPMENT				INTENSIVE DEVELOPMENT			
			UAL 1976	SBL 1976	UAL 2001	SBL 2001	UAL 2031	SBL 2031	UAL 2001	SBL 2001	UAL 2031	SBL 2031
Main Stem of Grand River												
Upper Grand	GA101-0102	68898	57.2	3941.0	33.9	2333.6	171.6	11824.4	139.7	9627.7	415.2	28609.3
Upper Grand	GA0103	13400	24.2	324.3	576.5	7725.1	910.8	12205.1	866.6	11612.5	1535.3	20572.4
Middle Grand	GA0104	36752	459.9	16902.2	944.1	34696.3	1316.6	48388.5	1397.2	51349.4	2142.4	78738.0
Middle Grand	GA0107-0110	50973	-	-	771.8	39338.2	771.8	39338.2	843.1	42977.4	843.1	42977.4
Lower Grand	GA0111	9617	-	-	998.1	9598.4	998.1	9598.4	1130.9	10875.7	1130.9	10875.7
Lower Grand	GB0101-0103	78877	-	-	587.7	46356.3	649.2	51203.2	940.9	74216.0	1063.8	83909.7
Tributaries												
Canagagigue	GA0105-0106	10761	292.2	3144.4	725.9	7810.9	725.9	7810.9	924.0	9943.6	924.0	9943.6
Conestogo	GA0601	27707	723.9	20057.1	182.4	5054.7	408.7	11323.4	383.8	10632.7	836.1	23166.0
Conestogo	GA0602	28829	-	-	686.6	19794.4	1127.7	32510.7	962.9	27758.4	1845.2	53195.1
Conestogo	GA0603-0604	26562	416.1	11052.4	1176.4	31247.0	1368.6	36353.5	1590.0	42233.7	1974.7	52451.0
Speed	GA0401-0402	27853	50.7	1412.1	1056.0	29411.6	1160.8	32331.9	1422.9	39630.7	1632.6	45471.4
Speed	GA0403-0408	22977	-	-	376.7	8654.5	376.7	8654.5	373.1	8571.9	373.1	8571.9
Eramosa	GA05	26505	45.9	1216.6	297.3	7880.4	413.1	10949.6	604.9	16031.6	839.3	22165.7
Aberfoyle	GA0301-0304	9926	26.6	264.0	212.7	2110.9	218.2	2165.7	434.0	4307.9	445.8	4422.5
Nith	GA0201-0210	114617	693.7	79509.8	952.4	109158.6	1098.8	125937.6	1168.6	133942.9	1461.4	167500.9
Whiteman	GB0501-0502	40754	167.9	6842.6	-	-	-	-	-	-	-	-
Big and Fairchild	GB03-04	58878	-	-	793.4	46716.1	811.9	47799.9	921.1	54233.9	957.9	56401.4
McKenzie	GB0201	20297	207.3	4207.6	-	-	-	-	-	-	-	-
Boston	GB0202	23083	-	-	712.4	16443.5	948.3	21889.9	953.7	22015.1	1425.6	32907.9
	TOTAL	697266		279900.0		407887.0		510285.4		569961.1		741879.9

Table 23. Extrapolation of Unit Area Loads (UAL, kg/ha/year) and Sub-Basin Loads (SBL, t/year) of Total Phosphorus

Sub-basin		SUB-BASIN AREA ha	MEASURED		MODEST DEVELOPMENT				INTENSIVE DEVELOPMENT			
			UAL 1976	SBL 1976	UAL 2001	SBL 2001	UAL 2031	SBL 2031	UAL 2001	SBL 2001	UAL 2031	SBL 2031
Main Stem of Grand River												
Upper Grand	GA0101-0102	68898	0.25	17.2	0.58	40.2	0.60	41.0	0.60	41.0	0.62	42.4
Upper Grand	GA0103	13400	-	-	0.66	8.9	0.69	9.2	0.68	9.1	0.73	9.8
Middle Grand	GA0104	36752	0.62	22.8	0.53	19.6	0.58	21.3	0.59	21.6	0.68	24.9
Middle Grand	GA0107-0110	50973	-	-	0.56	28.7	0.59	30.2	0.60	30.8	0.66	33.7
Lower Grand	GA0111	9617	-	-	0.11	1.1	0.11	1.0	0.12	1.2	0.12	1.1
Lower Grand	GB0101-0103	78877	-	-	0.80	63.2	0.81	63.6	0.83	65.3	0.84	66.0
Tributaries												
Canagagigue	GA0105-0106	10761	0.84	9.0	0.60	6.5	0.65	6.9	0.67	7.2	0.75	8.1
Conestogo	GA0601	27707	0.92	25.5	0.74	20.5	0.77	21.3	0.77	21.4	0.83	23.0
Conestogo	GA0602	28829	0.25	7.2	1.00	28.7	1.05	30.2	1.03	29.6	1.13	32.6
Conestogo	GA0603-0604	26562	0.80	21.2	1.04	27.5	1.08	28.8	1.07	28.4	1.16	30.9
Speed	GA0401	27853	0.13	3.6	0.47	13.1	0.49	13.7	0.54	15.0	0.58	16.2
Speed	GA0403-0408	22977	-	-	0.25	5.8	0.26	6.1	0.27	6.2	0.30	6.9
Eramosa	GA05	26505	0.16	4.2	0.22	5.8	0.24	6.3	0.26	6.9	0.30	7.8
Aberfoyle	GA0301-0304	9926	0.07	0.7	0.09	0.9	0.10	1.0	0.12	1.2	0.14	1.3
Nith	GA0201-0210	114617	1.21	138.7	0.74	84.2	0.76	87.5	0.77	88.0	0.82	94.5
Whiteman	GB0501-0502	40754	0.40	16.3	0.51	20.6	0.49	20.1	0.53	21.8	0.52	21.2
Big and Fairchild	GB03-04	58878	-	-	0.69	40.9	0.70	40.9	0.70	41.4	0.71	41.6
McKenzie	GB0201	20297	0.36	7.3	0.59	12.0	0.59	12.0	0.62	12.5	0.63	12.7
Boston	GB0202	23083	-	-	0.80	18.5	0.82	18.9	0.82	18.9	0.86	19.7
	TOTAL	679266		257.0		426.1		460.0		467.5		494.3

Table 24. Extrapolation of Unit Area Loads (UAL, kg/ha/year) and Sub-Basin Loads (SBL, t/year) of Filtered Reactive Phosphorus

Sub-basin		SUB-BASIN AREA ha	MEASURED		MODEST DEVELOPMENT				INTENSIVE DEVELOPMENT			
			UAL 1976	SBL 1976	UAL 2001	SBL 2001	UAL 2031	SBL 2031	UAL 2001	SBL 2001	UAL 2031	SBL 2031
Main Stem of Grand River												
Upper Grand	GA0101-0102	68898	0.02	1.5	0.11	7.6	0.12	8.0	0.12	8.0	0.13	8.7
Upper Grand	GA0103	13400	0.12	1.6	0.15	2.0	0.16	2.1	0.16	2.1	0.18	2.5
Middle Grand	GA0104	36752	0.04	1.7	0.12	4.3	0.14	5.1	0.14	5.3	0.19	7.0
Middle Grand	GA0107-0110	50973	0.11	14.9	0.13	6.4	0.14	7.1	0.15	7.4	0.18	9.0
Lower Grand	GA0111	9617	-	-	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Lower Grand	GB0101-0103	78877	-	-	0.18	14.5	0.19	14.7	0.20	15.6	0.20	16.0
Tributaries												
Canagagigue	GA0105-0106	10761	0.43	5.2	0.15	1.7	0.18	1.9	0.19	2.0	0.23	2.5
Conestogo	GA0601	27707	0.20	5.4	0.17	4.6	0.18	5.0	0.18	5.1	0.21	5.9
Conestogo	GA0602	28829	0.23	6.6	0.27	7.9	0.30	8.6	0.29	8.4	0.34	9.9
Conestogo	GA0603-0604	26562	0.26	5.4	0.31	8.2	0.33	8.8	0.33	8.6	0.37	9.9
Speed	GA0401-0402	27853	0.01	0.1	0.09	2.5	0.10	2.9	0.12	3.4	0.15	4.1
Speed	GA0403-0408	22977	-	-	0.00	0.0	0.01	0.2	0.01	0.3	0.03	0.6
Eramosa	GA05	26505	-	-	0.00	0.0	0.00	0.0	0.01	0.2	0.03	0.7
Aberfoyle	GA0301-0304	9926	0.01	0.1	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
Nith	GA0201-0210	114617	0.25	25.0	0.18	21.1	0.20	22.8	0.20	23.1	0.23	26.5
Whiteman	GB0501-0502	40754	0.10	3.9	0.10	4.2	0.10	3.9	0.12	4.8	0.11	4.5
Big and Fairchild	GB03-04	58878	-	-	0.16	9.2	0.16	9.2	0.16	9.5	0.16	9.6
McKenzie	GB0201	20297	0.09	1.8	0.13	2.6	0.13	2.6	0.14	2.8	0.15	2.9
Boston	GB0202	23083	-	-	0.19	4.3	0.20	4.5	0.20	4.5	0.21	4.9
	TOTAL	697266		102.0		101.0		107.4		111.1		125.2

Table 25. Extrapolation of Unit Area Loads (UAL, kg/ha/year) and Sub-Basin Loads (SBL, t/year) of Total Kjeldahl Nitrogen

Sub-basin		SUB-BASIN AREA	MEASURED		MODEST DEVELOPMENT				INTENSIVE DEVELOPMENT			
		ha	UAL 1976	SBL 1976	UAL 2001	SBL 2001	UAL 2031	SBL 2031	UAL 2001	SBL 2001	UAL 2031	SBL 2031
Main Stem of Grand River												
Upper Grand	GA0101-0102	68898	2.42	166.0	2.93	201.8	2.99	205.7	2.99	205.9	3.10	213.6
Upper Grand	GA0103	13400	4.63	62.0	3.33	44.7	3.47	46.5	3.46	46.3	3.73	49.9
Middle Grand	GA0104	36752	1.90	69.8	3.04	111.6	3.30	121.3	3.35	123.0	3.88	142.4
Middle Grand	GA0107-0110	50973	-	-	3.19	162.4	3.38	172.2	3.45	175.8	3.83	195.4
Lower Grand	GA0111	9617	-	-	1.47	14.2	1.43	13.7	1.53	14.7	1.48	14.2
Lower Grand	GB0101-0103	78877	-	-	3.72	293.5	3.75	295.5	3.86	304.8	3.91	308.7
Tributaries												
Canagagigue	GA0105-0106	10761	3.76	40.5	3.50	37.7	3.79	40.8	3.91	42.1	4.49	48.4
Conestogo	GA0601	27707	3.61	100.0	3.55	98.3	3.72	102.9	3.75	103.8	4.08	113.1
Conestogo	GA0602	28829	3.46	99.7	4.68	134.8	4.98	143.5	4.87	140.4	5.47	157.8
Conestogo	GA0603-0604	26562	4.76	126.4	5.11	135.8	5.40	143.5	5.29	140.5	5.87	156.0
Speed	GA0401-0402	27853	-	-	2.72	75.6	2.85	79.5	3.12	86.9	3.40	94.6
Speed	GA0403	22977	-	-	1.85	42.5	1.94	44.5	1.97	45.3	2.15	49.5
Eramosa	GA05	26505	-	-	1.69	44.7	1.79	47.5	1.92	51.0	2.14	56.7
Aberfoyle	GA0301-0304	9926	1.27	12.6	1.21	12.0	1.26	12.5	1.36	13.5	1.47	14.6
Nith	GA0201-0210	114617	5.16	591.4	3.77	432.2	3.95	452.4	3.97	455.0	4.32	495.3
Whiteman	GB0501-0502	40754	3.16	128.8	2.86	116.7	2.78	113.3	3.01	122.8	2.93	119.3
Big and Fairchild	GB03-04	58878	-	-	3.45	203.3	3.46	203.8	3.51	206.4	3.52	207.3
McKenzie	GB0201	20297	2.36	47.9	3.05	61.9	3.07	62.3	3.21	65.1	3.25	65.9
Boston	GB0202	23083	-	-	3.74	86.3	3.83	88.5	3.84	88.6	4.03	93.0
	TOTAL	697266		1971.1		2310.0		2389.9		2431.9		2595.7

Table 26. Extrapolation of Unit Area Loads (UAL, kg/ha/year) and Sub-Basin Loads (SBL, t/year) of Filtered Nitrite and Nitrate

Sub-basin		SUB-BASIN AREA ha	MEASURED		MODEST DEVELOPMENT				INTENSIVE DEVELOPMENT			
			UAL 1976	SBL 1976	UAL 2001	SBL 2001	UAL 2031	SBL 2031	UAL 2001	SBL 2001	UAL 2031	SBL 2031
Main Stem of Grand River												
Upper Grand	GA0101-0102	68898	2.17	147.3	4.90	337.4	5.49	378.6	5.53	381.0	6.73	463.4
Upper Grand	GA0103	13400	2.28	30.6	8.51	114.0	9.96	133.4	9.77	130.9	12.67	169.8
Middle Grand	GA0104	36752	9.09	426.8	12.42	456.6	15.25	560.6	15.77	579.6	21.44	787.8
Middle Grand	GA0107-0110	50973	9.92	1309.5	12.75	650.1	14.81	755.2	15.58	794.1	19.70	1004.3
Lower Grand	GA0111	9617	-	-	10.09	97.0	9.57	92.0	10.66	102.5	10.14	97.6
Lower Grand	GB0101-0103	78877	-	-	5.48	432.1	5.74	453.1	7.01	553.0	7.54	595.0
Tributaries												
Canagagigue	GA0105-0106	10761	15.98	194.2	17.80	191.5	20.91	225.1	22.22	239.2	28.46	306.2
Conestogo	GA0601	27707	4.61	126.3	6.41	177.5	8.22	227.7	8.54	236.5	12.16	336.8
Conestogo	GA0602	28829	8.37	238.6	12.92	372.4	16.15	465.6	15.00	432.4	21.47	618.9
Conestogo	GA0603-0604	26562	13.66	283.6	20.40	541.9	23.53	624.9	22.31	592.7	28.56	758.7
Speed	GA0401-0402	27853	3.57	20.1	10.13	282.0	11.61	323.3	14.48	403.3	17.44	485.7
Speed	GA0403-0408	22977	-	-	6.70	153.9	7.67	176.2	8.04	184.7	9.98	229.4
Eramosa	GA05	26505	-	-	5.33	141.4	6.49	172.1	7.89	209.1	10.21	270.5
Aberfoyle	GA0301-0304	9926	1.57	4.9	4.56	45.2	5.11	50.8	6.22	61.7	7.34	72.8
Nith	GA0201-0210	114617	10.07	1023.5	12.91	1479.3	14.79	1695.6	15.03	1723.2	18.81	2155.8
Whiteman	GB0501-0502	40754	11.86	446.7	10.96	446.8	10.05	409.7	12.56	512.0	11.65	474.8
Big and Fairchild	GB03-04	58878	-	-	8.22	484.1	8.30	488.8	8.78	516.7	8.94	526.1
McKenzie	GB0201	20297	5.11	102.5	8.73	177.2	8.95	181.7	10.41	211.4	10.86	220.3
Boston	GB0202	23083	-	-	5.92	136.6	6.94	160.2	6.96	160.8	9.01	208.0
	TOTAL	697266		5186.6		6717.0		7574.6		8024.8		9781.9

Grand River basin. Projected unit area loads of suspended solids are above 500 kg/ha/year for most sub-basins and some projected values are close to 2000 kg/ha/year.

4. Relatively large increases of row crops area are projected in part of the main stem of the Grand River (sub-basins GA0103, GA0104, GB0101, GB0102 and GB0103) and the Conestogo River. For these sub-basins, large increases of unit area loads are anticipated.

5. For part of the middle Grand River (sub-basins GA0107 to GA0110), the Speed River below Guelph and Aberfoyle Creek, extensive agricultural development is considered unlikely. For these sub-basins, low intensities of row crop cultivation and low unit area loads of suspended solids are predicted.

6. For the lower Grand River, Canagagigne Creek, Whiteman Creek, Big Creek, Fairchild Creek and McKenzie Creek; row crop areas projected to the year 2031 are slightly larger than or the same as those projected to the year 2001. The reason is that no increase in row crop area is projected in a sub-basin when the upper limit on land suitable for row crop production is reached. For these sub-basins, the unit area loads projected to 2001 are slightly less than or the same as those projected to 2031.

7. The above projected unit area loads of suspended solids assume that present agricultural practices will prevail in the future. A radical change in agricultural practices with the introduction of minimum tillage and other remedial measures could drastically alter the picture.

Based on tables 20, 21 and 23, the following observations were made concerning the extrapolation of total phosphorus loads:

1. The measured unit area loads of total phosphorus for 1976 were less than 0.6 kg/ha/year in most sub-basins with the exception

of Canagagigue Creek, the lower Conestogo River and the Nith River. In these sub-basins, phosphorus inputs resulting from the application of fertilizer and manure were above 20 kg/ha/year. Soil clay contents are high (above 24%) in the Conestogo River and the upper Nith River.

2. For the second agricultural land use scenario, (modest development) projected total phosphorus inputs (from fertilizer and manure) for the years 2001 and 2031 are above 20 kg/ha/year in the middle Grand River, Canagagigue Creek, the lower Conestogo River and the Nith River. For these sub-basins, the projected unit area loads of total phosphorus are above 0.6 kg/ha/year. Unit area loads exceeding 1 kg/ha/year are projected in the lower Conestogo River where the projected phosphorus inputs and soil clay content are high.

3. For the first agricultural land use scenario (intensive development) phosphorus inputs (from fertilizer) projected to the years 2001 and 2031 are greater than 20 kg/ha/year in the Middle Grand River, Canagagigue Creek, the lower Conestogo River, upper Speed River, the Nith River, Whiteman Creek and McKenzie Creek. For these sub-basins, the projected unit area loads of total phosphorus are above 0.6 kg/ha/year. In the Conestogo River basin where the soil clay content is high, the projected unit area load is approximately 1.2 kg/ha/year. For other sub-basins where total phosphorus inputs and the soil clay content are small the projected unit area loads are less than 0.6 kg/ha/year.

Based on Tables 20, 21 and 24, the following observations were made regarding the extrapolation of filtered reactive phosphorus loads:

1. Measured unit area loads of filtered reactive phosphorus for 1976 were less than 0.15 kg/ha/year in all sub-basins except Canagagigue Creek, the Conestogo River and the Nith River. In these three sub-basins phosphorus inputs resulting from the application of fertilizers and manure range from 20 kg/ha/year

to 32 kg/ha/year; the projected basin average is approxinately 16 kg/ha/year. Soils in the Conestogo River and the upper Nith River watershed also have relatively high clay contents (above 24.0%).

2. For the first land use scenario (intensive development), projected phosphorus inputs resulting from the application of fertilizer and manure range from 12.0 kg/ha/year to 47.3 kg/ha/year. For those sub-basins which have high soil clay contents and high phosphorus inputs (the Conestogo River, the Nith River), the projected unit area loads of filtered reactive phosphorus are greater than 0.20 kg/ha/year. For those sub-basins which have either high soil clay contents or high phosphorus inputs, the projected unit area loads range from 0.10 kg/ha/year to 0.20 kg/ha/year.

3. For the first land use scenario (intensive development), the annual loads of filtered reactive phosphorus contributed by all agricultural non-point sources in the Grand River basin were estimated at 111 t/year for the year 2001 and 125 t/year for the year 2031. For the second land use scenario, the corresponding load estimates are 101 t/year for 2001 and 107 t/year for 2031.

Based on Tables 20, 21 and 25, the following observations were made concerning the extrapolation of total Kjeldahl nitrogen loads:

1. The measured unit area loads for the year 1976 range from 1.27 kg/ha/year to 5.16 kg/ha/year. High unit area load values are observed in part of the upper Grand River, Canagagigue Creek, the Conestogo River and the Nith River. The estimated nitrogen inputs in these sub-basins are high (above 50 kg/ha/year). Soil clay contents in the upper Grand River, the Conestogo River and the upper Nith River are among the highest in the whole Grand River.

2. For the first land use scenario (intensive development), the nitrogen inputs projected for the years 2001 and 2031 are above 50 kg/ha/year for most sub-basins. The projected unit area loads range from 1.4 kg/ha/year to 5.9 kg/ha/year. Total basin load is estimated at 2432 t/year for 2001 and 2596 t/year for 2031.

3. For the second land use scenario (modest development), nitrogen inputs projected to the years 2001 and 2031 range from 31.9 to 139.7 kg/ha/year. The projected unit area loads range from 1.2 to 5.4 kg/ha/year. High unit area loads are projected for those sub-basins which have high soil clay contents as well as large nitrogen inputs. For this scenario, the total basin load is estimated at 2310 t/year for the year 2001 and 2390 t/year for the year 2031.

Based on Tables 20, 21 and 26, the following observations were made regarding the extrapolation of filtered nitrite and nitrate loads:

1. Measured unit area loads for the year 1976 were below 10.0 kg/ha/year in most sub-basins with the exception of Canagagigue Creek. The estimated nitrogen inputs (resulting from the application of fertilizer and manure) in these four sub-basins range from 58.0 kg/hg/year to 111.0 kg/ha/year. These input values are high compared with those in the remaining sub-basins. Total sub-basin load for the year 1976 is estimated at 5186 t/year.

2. For the first land use scenario (intensive development), the projected nitrogen inputs for the years 2001 and 2031 are above 60 kg/ha/year in most sub-basins except in part of the upper and lower Grand River, the lower Speed River, the Eramosa River, Aberfoyle Creek, Big Creek, Fairchild Creek and Boston Creek. The projected unit area loads for those sub-basins which have small nitrogen inputs are below 10 kg/ha/year. For the remaining sub-basins wherein nitrogen inputs are high, the projected unit area loads range from 10.2 kg/ha/year to 28.5

kg/ha/year. For this land use scenario, the total basin load is estimated at 8024 t/year for the year 2001 and 9782 t/year for the year 2031.

3. For the second land use scenario (modest development), the projected nitrogen inputs for the years 2001 and 2031 are above 60 kg/ha/year in the middle Grand River, Canagagigue Creek, the lower Conestogo River, the upper Speed River, the Nith River and Whiteman Creek. Unit area loads projected for these sub-basins range from 10.0 kg/ha/year to 23.5 kg/ha/year. The projected values for the remaining sub-basins are below 10.0 kg/ha/year. For this scenario, the total bain load is estimated at 6770 t/year for the year 2001 and 7575 t/year for the year 2031.

8. REMEDIAL MEASURES

The thrust of remedial measures in agricultural areas must be directed towards the protection of the land resources from water and wind erosion. This can be achieved by sensible soil conservation practices which hold the rainfall on the land in the soil where it cannot contribute to floods, erosion and sedimentation problems. In doing so, benefits accrue to other purposes namely improved water quality in receiving streams. Effective remedial measures include the use of special erosion control structures, soil management and crop cover management.

Remedial measures can be classified as structural, non-structural or a combination of both. Not all remedial measures will fit every farm management scheme. However, each erosion problem can be reduced by choosing one or more of the remedial practices available. The choice of any such practices should be appropriate to the problem at hand and must be economical and practical at the same time. A brief description of the most common agricultural remedial measures is given in the following paragraphs based on a report prepared by Marshall Macklin Monaghan Limited (1977).

8.1 STRUCTURAL PRACTICES

Practices which are primarily structural involving a one-time cost of installation are described below.

Stream Bank Protection

Unstable banks of streams or excavated channels are protected either through the use of vegetative cover or through structural activities such as plating of the bank with stone or similar material. Grass vegetation costs from $\$0.25/m^2$ to $\$0.30/m^2$ whereas rip-rap costs from $\$9.00/m^2$ to $\$18.00/m^2$.

Grassed Waterways

Grassed waterways are broad, shallow channels in the soil vegetated with grass or legumes. They are constructed with shallow grades to slowly conduct water down slopes. The vegetation in the channel retards the flow and resists the soil cutting actions of the water.

In order to establish a stable vegetative cover on a waterway, seed should be broadcast or drilled non-parallel to the direction of water flow. In addition, a straw mulch should be applied after seeding. The cost of seeding ranges from $\$0.20/m^2$ to $\$0.80/m^2$ whereas wood and straw mulch costs about $\$0.18/m^2$.

Livestock Exclusion

Livestock exclusion involves fencing drainage ditches or natural streams so that livestock cannot graze banks, disturb sediments in the bottom of the waterway or defecate directly into the waterway. Alternate livestock watering facilities are often needed so as to provide a source of drinking water for the livestock fenced out of the waterway.

The cost of fencing is estimated at $1.50 to $2.75 per meter of fence.

Field Border Strips

The functions of a vegetative strip established along the edge of a field are to slow down surface runoff and filter out sediment carried in it. A vegetative strip is particularly effective when established along ditch banks. It also reduces stream bank erosion by stabilizing the upper zones of the bank.

Where a vegetative strip removes available land from crop production, the loss of profit to the farmer must be considered in addition to the cost of vegetative strip installation. However, the loss of profit may be small if a hay crop is used as a buffer strip.

Sediment Control Basins

Sediment control basins can be formed by the construction of barriers or dams across waterways or by the routing of water from a waterway through a man-made pond. The function of sediment control basins is to retain runoff for a period of time, thereby allowing sediment to settle out.

The cost of sediment control basins varies according to the size of the basin, the type of lining materials used and the type of control structures employed.

Check Dams

A check dam is a structure used to reduce the gradients in channels to thereby control streambank erosion. At the drop structure an abrupt change in grade is created in a localized area which is protected from ersoion. Check dams are used where excessive grade or overfall conditions occur or where water is to be lowered from one elevation to another. Structures can be made of concrete, metal rock, gabions, wood; depending upon site conditions.

The cost of a check dam is site specific and dependant on design. The design life of such dams ranges from 5 to 50 years. The operating and maintenance cost ranges from 1% to 2% of the capital costs per year.

Parallel Terraces

Parallel terraces is the term applied to a series of terraces constructed across a slope at a suitable spacing and grade to reduce soil erosion. These terraces can be constructed in areas where the slope of the land can be increased in small areas and decreased over larger areas which can be used for intensive cropping. On gently sloping hillsides, terraces may be tens of metres wide, whereas on steep slopes, they many be less than 5 m wide. This technique is

generally considered impractical on land slopes over 10%-20% because the steeper back slopes tend to negate the benefits of the terrace.

The cost of terraces is estimated from $120 to $250 per hectare.

8.2 NON-STRUCTURAL PRACTICES

Conservation Tillage

For centuries the moldboard plough has been the basic tool of agriculture, breaking and turning the soil as the first step in the series of operations collectively known as tillage. On a large and growing area of farm land, however, the plough is being displaced by a system of farming that involves reduced amounts of tillage or none at all.

Conservation tillage, in general, can result in significantly reduced soil erosion, though to a lesser extent than that possible when tillage practices are combined with cropping practices beneficial to soil structure, such as crop rotations and cover crops (Vyn, 1979).

Within tillage systems there are three approaches which have usually been advocated to reduce the erosion potential of the surface soil. They are: (a) changing tillage direction from up and down to across the slope; (b) leaving the soil surface rough and porous; and (c) leaving crop residues on the surface. There are considerable differences in the effectiveness of the various approaches (Vyn, 1981).

Crop Residue Management

When left on the soil surface, crop residues (such as corn stover, small grain and soybean straws, and sorghum stalks) reduce soil erosion by providing a canopy to curtail soil detachment and by reducing the velocity of surface runoff. In addition, crop residues act as a windbreak, thereby reducing soil erosion caused by wind.

Cover Crops

Cover crops, whether winter or summer, are beneficial in controlling soil erosion since they: a) provide a rapid canopy cover to reduce the impact of water droplets as well as reduce the flow of runoff water; b) add organic matter to the soil; c) improve the structural stability of the surface soil such that the soil is less susceptible to water erosion.

Winter cover crops such as fall rye are especially attractive when previous field crops (i.e. soybeans, silage corn and tobacco) do not provide adequate residue after harvest, thus, soil erosion cannot be controlled by conservation tillage systems. Further, winter cover crops are also attractive when winter cereal crops such as winter wheat are not feasible.

Fall rye can be successfully established during September or early October by broadcasting on the soil surface prior to or following grain harvest or by seeding with a grain drill following harvest of the previous crop. Establishment costs are minimal. Winter cover crops can be ploughed under or killed with herbicides the following spring. Zero tillage may be more effective on medium to fine-textured soils when corn is established on a cover crop.

Crop Rotation

Since sod crops such as hay and pasture keep soil erosion to a minimum, substantial soil loss reduction can be effected by converting a continuous row crop system to a sod-based rotation. At the same time, a good crop rotation can slow the buildup of weeds, insect and disease problems encountered with a continuous cropping system. When incorporated into the soil, sod crops can provide another secondary benefit in that the structural stability and internal drainage of the soil is improved.

Stripcropping

Stripcropping is practised as a means of reducing erosion on tilled, sloping soils. The intent is to break the length of slope into

segments by laying out strips across the natural slope of the land. Strips of close-growing crops (forage crops) are planted alternately between tilled row crop strips to serve as buffer strips in slowing water flow and, therefore, controlling erosion and reducing soil loss. Stripcropping can effect a soil loss reduction up to 85%. This practice effectively reduces the velocity of water as it leaves each tilled strip. More surface runoff is absorbed and soil particles have less chance of being transported.

The system of stripcropping, where the strips are layed out on the contour, or nearly perpendicular to the direction of the slope on fields with complex slopes, is referred to as contour stripcropping. With any type of stripcropping, the strips can vary in width to accomodate the degree of slope, soil type and width of farm equipment. Stripcropping is also effective in controlling wind erosion where strips can be placed perpendicular to the prevailing wind direction. The cost of stripcropping was estimated at $25/ha which includes capital costs and potential loss in profit.

Contour Cropping

By cropping parallel to the contour of the land, runoff which would normally flow perpendicular to the contour is diverted laterally to take much longer, slower routes to its eventual outlet thereby increasing infiltration, reducing erosion and soil loss. This technique can reduce average soil loss by 50% on moderate slopes but less on steep slopes. It allows more intensive cropping without a decline in productivity.

8.3 PROPOSED REMEDIAL MEASURES FOR THE GRAND RIVER BASIN

It is clear from the above description of remedial measures that pollution from rural diffuse sources can be reduced by various means. Several remedial measures can be tailor-made for a specific location. Recent studies (Wall et al, 1978) found that only a small percent of an agricultural watershed (10.0% - 20.0%) contributes to the majority of the sediment load to stream channels. These areas

are referred to as "hydrologically active areas". Remedial measures are most cost-effective if they are applied to these areas.

Based on the state of agricultural activities in the Grand River basin, one can distinguish between two categories of sub-basins: those presently under intensive agricultural development and those which are still in the developing stage. Each one of these categories requires a different scheme for diffuse source control.

8.3.1 Sub-basins With Intensive Agricultural Development

Sub-basins placed under this category include a section of the Grand River between the Village of West Montrose and Brantford, the lower Conestogo River, the Nith River, Canagagigue Creek, McKenzie Creek and Whiteman Creek. At present, the percentage of row crops in these sub-basins ranges from 20.0% to 31.6% of the sub-basin area. Under the intensive development scenario (see Section 7.3), the projected row crop area would constitute from 27.9% to 51.2% of the sub-basins area.

As was mentioned in Section 8.3, good management practices are most effective if they are implemented in these sub-basins specifically in the so-called "hydrologically active areas". The objective of the Grand River Basin Water Management Study did not include, due to manpower, time and cost constraints, a site-specific identification of all the hydrologically active areas within the basin. Nevertheless, a number of problems have been identified in several sub-basins, through field surveys and aerial photograph interpretation; and certain remedial measures are proposed. These measures are:

1. Conservation tillage and crop residue management,

2. Stream bank stabilization,

3. Flood plain management,

4. Restriction of cattle access to streams,

5. Establishment of buffer strips.

8.3.1.1 Conservation Tillage

The most important factor that determines the effectiveness of tillage practices in reducing soil erosion is the amount and distribution of crop residues remaining on the soil surface. The need for adoption of conservation till systems increases on land with steeper slopes and less stable surface soil (Vyn, 1981).

From the different conservation tillage practices evaluated by PLUARG (Wall et al, 1978) for a continuous grain corn crop, zero tillage has been found to be the most effective practice in reducing annual soil loss (79%), followed by the disk-plant method (70%). Rotary strip tillage has the potential of reducing average annual soil losses by half and chisel ploughing by about 30%.

The Honey Creek Watershed Project (1979) also showed that erosion reduction with reduced or no-tillage practices can be significant. From measurements obtained from 19 plots of land, 14 showed an estimated soil loss reduction of 50% or more while 7 plots showed reductions of 75% or more. No plots showed an increase in soil loss. This data suggests that on site retention of nutrients, particularly phosphorus, would be markedly greater, as well.

Vyn (1981) in a recent study on tillage practices in the Grand River basin recommended that the adoption of specific tillage practices should be based on soil type. The practice of zero tillage on coarse, sandy soils and either chisel ploughing or off-set disking on loam soils should result in corn grain yields equivalent to that achieved after moldboard ploughing. Both chisel plough and off-set disk tillage systems can reduce soil erosion losses up to 75% when compared to conventional tillage. However, the consistent yield reductions experienced with conservation tillage systems on sandy loam, clay loam and clay soil textures make the alternative systems economically unattractive in the short term. Other alternatives may be necessary on these soil types if they are contributing significant amounts of sediment and phosphorus to the Grand River.

Coarse sands and gravelly loams are found mainly in the middle Grand River sub-basin. These soils are associated with spillways, eskers, kames and outwash deposits. Zero tillage will result in similar or even higher yields than conventional tillage. Loam soils are predominant in the Speed River and middle Grand River sub-basins. The combinations of fall chiselling plus spring secondary tillage, or spring off-set disking plus harrowing or spring plough-planting have all given yields similar to conventional tillage. Clay loam and clay soils are predominant in the Conestogo River, upper Nith River and lower Grand River sub-basins. For these soils, conservation tillage practices do not appear to be economically feasible.

The economics of reduced and no-tillage practices are dependant on two major factors: the amount of crop yield reduction, if any, which accompanies the change in tillage; and, the market value of the crop produced.

When a significant yield reduction accompanies the change in tillage practice, the dollar cost of sustaining that yield reduction will be higher when crop prices are high and lower when market prices are relatively low. In the Honey Creek Watershed Project (1979), of the 31 reduced and no-tillage plots that were investigated with corn and soybean cropping systems, 28 showed positive net return ranging from $40 to $170 per acre and averaging $97 per acre. Net losses from the other 3 plots ranged from $9 to $36 per acre, averaging $19 per acre. In these three plots, minor changes in management steps would seemingly produce positive net returns as well. There were two field conventional tillage plots to make accurate comparison between conventional and reduced tillage performances. However, it was felt that reduced till and no-till tillage systems were at least as profitable to the farmers as the conventional tillage system in the area.

The majority of the tillage experiments conducted to date in Ontario have used corn. Corn grain yields, resulting from different tillage

systems, are dependent on soil texture. Table 27 shows the average corn grain yields in relation to various tillage practices on three soil types in central Ontario. Table 28 shows the effect of tillage on corn grain yield on clay loam and clay soil types. Little or no research information is available on tillage practices for other grain and oilseed crops in Ontario. After soybeans, the soil appears to be loose or "mellow" and frequently fall tillage may be unnecessary, except on fine-textured soils. Since surface soil is much more susceptible to water erosion after soybeans than after corn, conservation tillage systems are even more critical in soybean production (Vyn, 1979). Those farmers in the Grand River Basin who are concerned about the erosion susceptibility of soil following soybeans, and with the amount of residue following corn, may consider alternating between moldboard and chisel ploughing in a corn-soybean rotation on fine-textured soils, moldboard ploughing after corn and chisel ploughing after soybeans.

Tillage costs are relatively low in comparison to total crop production costs. According to the 1981 Crop Budget Aids prepared by personnel of the Ontario Ministry of Agriculture and Food, conventional tillage represents 6.6 and 8.4% of the total production costs for corn and soybeans, respectively. Chisel ploughing would only reduce fuel consumption by 20% (approximately 2l/ha), assuming equal depths of chisel and moldboard ploughing and identical secondary tillage prior to planting (Vyn et al, 1979). Utilizing the off-set disk would increase fuel consumption by 20 to 30% over moldboard ploughing, but may result in lower overall fuel use if secondary tillage is reduced or eliminated entirely. Labour savings and timeliness advantages may be more important than actual reductions in fuel expenditures.

8.3.1.2 Streambank Stabilization

Continuous bank cover is perhaps the most widely used method for stream bank stabilization. A wide variety of cover materials is available. Some of these materials are permeable, such as

Table 27. Average Corn Grain Yields in Relation to Various Tillage Practices on Three Soil Types in Central Ontario (Vyn, 1981)

Tillage Treatment	Soil Texture (Years) Sandy Loam (1976-80)	Loam (1976-79)	Silt Loam (1976-80)
	--------Grain Yield (t/ha)*---------		
Fall moldboard plow; spring disc, harrow	6.2	5.6	5.4
Fall chisel plow; spring disc, harrow	5.9	5.6	5.1
Spring moldboard plow only	6.0	5.6	4.7
Spring moldboard plow, disc and harrow	5.9	5.4	5.2
Spring off-set disc, harrow	5.9	5.5	5.0
Zero tillage	5.4	5.0	4.5

*Grain yields are reported as dry matter yields (i.e., 0% moisture).

Table 28. Effect of Tillage on Grain Corn Yield on Clay Loam and Clay Soil Type (Vyn, 1981)

Tillage Treatment	Soil Texture (Years) Clay Loam (1979-80)	Clay (1977-80)
	-----Grain Yield (t/ha)*------	
Fall moldboard plow plus spring secondary tillage of:		
- disc plus cultipack once	-	4.8
- disc plus cultipack twice	6.0	4.6
- disc plus cultipack four times	6.0	4.7
Fall chisel plow plus spring secondary tillage of:		
- disc plus cultipack twice	-	4.5
- disc plus cultipack four times	5.7	-
Spring moldboard plow, disc and cultipack	5.5	4.6
Zero tillage +	5.1	4.5

*Grain yields are reported as dry matter yields (i.e., 0% moisture).

+Due to severe crusting on all the tilled treatments in 1978, 1979 and 1980, the zero tillage treatment had significantly higher yields than would normally have been the case.

vegetation, rip rap, brush matting and gabions. Others are impermeable, such as asphalt, concrete and sheet piling; and they normally require subsurface drainage. The choice of cover materials is site-specific, depending on the causes and severity of bank erosion. For most of the unstable stream banks identified in the Grand River basin (mainly in the Conestogo River and the Nith River basins), a bank cover made of vegetation or rip rap would provide adequate protection.

Table 29 gives the costs of stream bank stabilization for the Nith River, Conestogo River and Irvine Creek. The table indicates the length of stream bank to be stabilized, the proposed stabilization methods, the costs per meter and the total costs. It is estimated that this remedial measure, if implemented in all of these sub-basins, would cost approximately $\$1.2 \times 10^6$ which is equivalent to \$4.70/m. Stabilization of stream banks could be a one-time initial cost, however, the useful life of these structures is not unlimited. Assuming a useful life of 20 years and a discount interest rate of 6% per annum, the equivalent amortized cost is approximately \$140,000 per year or \$0.50/m.

8.3.1.3 Flood Plain Management

Flood plain management is important for the simple reason that a flood plain is subject to frequent inundation. When used for intensive crop production that leaves soil exposed for a long period of time or involves the use of large quantities of fertilizers, a flood plain could contribute large loads of sediment and nutrients to the drainage way. An effective means to prevent this from happening is to pre-empt a flood plain from crop production. Additional reduction of sediment loss can be effected by maintaining a stable vegetative cover in the flood plain.

During the two field surveys, flood plain cropping was observed in the Nith River downstream of the Town of Wellesley. Non-conservation cropping practices such as up and down cropping, fall ploughing and fall application of fertilizers were observed in

Table 29.

Costs of Stream Bank Stabilization

Stream	Stream Length km	Stabilization Method	Length of Stream Bank to be Stabilized m	Unit Cost $/m	Total Cost $
1. Upper Nith River					
Main Channel	42.8	Vegetation (width of 15.2 m)	7275	2.17	15786.75
		Rip rap (width of 6.1 m)	7277	90.49	658495.73
Tributaries	129.9	Vegetation (width of 17.4 m)	46760	1.64	76686.40
		Rip rap (width of 1.0 m)	7793	10.24	79800.32
2. Lower Nith River					
Main Channel	75.0	Vegetation (width of 3.8 m)	8251	1.84	15181.84
		Rip rap (width of 1.7 m)	6751	24.57	165872.07
Tributaries	148.0	Vegetation (width of 2.3 m)	22134	1.05	23240.70
3. Conestogo River					
Main Channel	41.5	Vegetation (width of 6.2 m)	22011	0.69	15187.59
Tributaries	187.1	Vegetation (width of 3.1 m)	65475	0.62	40594.50
		Rip rap (width of 0.8 m)	3741	11.17	43807.11
4. Irvine Creek					
Main Channel	33.0	Vegetation (width of 1.6 m)	5614	0.03	168.42
Tributaries	98.7	Vegetation (width of m)	53321	1.57	83713.97
Total	756.0		256404	4.70	1218535.40

the flood plain between Wellesley and New Hamburg. It is estimated that the annual sediment load from this part of the Nith River basin (downstream of Wellesley) can be reduced by 10% to 20% if the production of row crops and small grains in the flood plain is stopped.

Table 30 gives the costs of discontinuing the production of small grains and row crops in the flood plain in the lower Nith River watershed. At present, 872 ha of land within the flood plain of the lower Nith River are used for crop production, 353 ha for small grains and 5.9 ha for row crops. Disallowing the production of small grains and row crops in this flood plain would result in an annual loss of profits of $226300 which is equivalent to $2.20/ha. This estimate is based on an assumed net return of $300/ha for row crops and $200/ha for small grains. An alternate scheme is to purchase this land from the farmers. Assuming that the cost of land ranges from $5000/ha to $12400/ha, this scheme would cost from $\$4.4 \times 10^6$ to $\$10.8 \times 10^6$.

Table 30 Costs of Discontinuing the Production of Small Grains and Rowcrops in the Flood Plain

Zone	Stream Length km	Area of Flood Plain ha	Land Use Distribution in Flood Plain (%)					Area of Crop land in Flood Plain		Costs of Discontinuing Crop Production in Flood Plain
			Other	Woods	Pasture	Small Grains	Row Crop	Small Grains ha	Row Crop ha	$/yr**
N4	26.2	701	12.0	15.2	54.3	6.5	12.0	46	84	34,400
N5	75.0	2009	2.4	26.5	48.2	4.8	18.1	96	364	128,400
N6	147.6	1476	0	11.9	69.0	14.3	4.8	211	71	63,500
Total	248.8	4186						353	519	226,300

* based on an assumed average flood plain width of 0.1 km
** based on crop net return values of $300/ha/yr for row crop and $200/ha/yr for small grains

8.3.1.4 Restriction of Cattle Access to Streams

Allowing cattle to have unrestricted access to streams often results in higher loadings of sediment, nitrogen, phosphorus and bacteria to the receiving streams. One way to solve this problem without re-locating livestock farms is to install fence along the receiving streams.

During field surveys, cattle access to streams was observed in many locations in the Conestogo River, Nith River and Irvine Creek basins. It is estimated that a 10% reduction of the annual sediment load from these sub-basins can be effected by installing fences to restrict cattle access to the streams.

From aerial photographs, the number of cattle operations within 90 m to 300.0 m of the channels of the Grand River, Canagagigue Creek, the Conestogo River and the Nith River was determined. The estimated costs of fencing are given in Table 31. These cost estimates are based on the assumptions that 100 meters of fence are needed in each cattle farm and that each meter of fence costs $2.20.

8.3.1.5 Establishment of Buffer Strips

A vegetative strip established along waterways acts as a filter. It traps a portion of the sediment carried by overland flow, thereby reducing the sediment load to the receiving stream. A reduction of 5% to 10% of the annual sediment load from the lower Conestogo River basin, the Nith River basin upstream of the town of New Hamburg, and Fairchild Creek can be effected by increasing the width of buffer strips in these sub-basins to 3.0 meters. The same effort in the middle Grand River basin and the lower Nith River basin would reduce the annual sediment loads from these sub-basins by about 5%.

Table 32 gives the costs of increasing the width of buffer strips to 3.0 meters in the Nith River, the Conestogo River and Irvine Creek watersheds. The area of crop land to be converted to buffer strips

Table 31. Costs of Fencing to Restrict Cattle Access to Streams

SUB-BASIN LOCATION	SUB-BASIN CODE	COSTS OF FENCING ALL CATTLE OPERATIONS WITHIN 90 m OF STREAMS*	COSTS OF FENCING ALL CATTLE OPERATIONS WITHIN 300 m OF STREAMS*
GRAND RIVER MAIN STEM			
above Lake Belwood	GA0102	1000	18400
above Shand Dam	GA0103	600	3600
above West Montrose	GA0104	4600	25600
above Cambridge	GA0107	1000	13000
TRIBUTARIES			
Canagagigue Cr. above Flordale	GA0106	1000	4400
Canagagigue Cr. below Flordale	GA0105	1400	13200
Conestogo R. above Conestogo Lake	GA0601	2000	24400
Conestogo R. above Conestogo Dam	GA0602	1600	23600
Conestogo R. below Conestogo Dam and	GA0603 GA0604	7600	42200
Nith R. N. of Shakespeare	GA0201	6600	35200
Nith R. at Canning and	GA0202 GA0210	9600	39200
Total		37000	242800

* Based on the assumption that 100 m of fence is required at each cattle operation and the fence costs $2/m.

Table 32. Costs of Increasing the Width of Buffer Strips to 3.0 m

Zone	Stream Length km	Length of Stream with cropland on both sides: Hay km	Small Grains km	Row Crops km	Length of Streams with crops on both sides and buffer strips less than 3.0 m wide: Hay km	Small Grains km	Row Crops km	Area of Croplands to be converted to buffer strips: Hay ha	Small Grains ha	Row Crops ha	Costs of increasing the width of buffer strips to 3.0 m: Crop loss* $/yr	Maintenance** $/yr	Total $/yr
N1	23.2	12.1	3.3	3.3	9.3	2.6	2.6	5.7	1.6	1.6	1912	88	2000
N2	54.1	11.3	10.1	7.4	9.3	8.3	6.1	5.7	5.1	3.7	3255	144	3399
N3	63.4	43.6	6.7	1.8	43.6	6.7	1.8	26.6	4.1	1.1	6457	317	6774
N4	32.0	16.9	2.1	4.2	15.2	1.9	3.7	9.3	1.2	2.3	2774	127	2901
N5	75.0	31.7	5.0	15.9	22.2	3.5	11.1	13.5	2.1	6.8	5160	224	5384
N6	147.6	66.9	24.2	18.3	42.1	15.3	11.5	25.7	9.3	7.0	9105	420	9525
C1	228.6	159.3	22.4	15.3	89.2	12.5	8.6	54.4	7.6	5.2	13975	673	14648
I	131.8	81.7	18.6	10.2	45.0	10.2	5.6	27.4	6.2	3.4	7746	370	8116
Total								168.3	37.2	31.1			

* Assumed crop loss values: $300/ha/year for row crops and $200/ha/year for grains and hay

** Assumed maintenance costs: $10/ha/year

in these watersheds is estimated to be 236.6 hectares which is being used for the production of row crops (13.1%), small grains (15.7%) and hay (71.2%). The loss of profit to the farmers due to the conversion of this crop land to buffer strips is approximately $50,000, assuming a net return of $300/ha/year for row crops and $200/ha/year for small grains and hay. The annual cost of maintaining the buffer strip is estimated to be $2,400. The sum of the value of crop loss and maintenance cost amounts to $52,700 per year.

The above annual costs are based on the assumption that the crop land converted to buffer strips remain the property of the farmers and compensation is paid for the loss of crop returns. A second financial scheme, however, is possible through the purchase of land. Such a scheme will cost from 1.2×10^6 to 2.9×10^6, assuming that the price of land ranges from $5000/ha to $12,400/ha. Under this scheme, the only additional cost required is maintenance cost which is approximately $2400 per year.

8.3.1.6 Summary

Table 33 summarizes the major causes of agricultural non-point source pollution in those sub-basins with intensive agricultural development, the proposed remedial measures and the estimated costs. The cost estimates are based on extrapolation of field survey observations and on assumptions regarding the cost of purchasing or renting farm land and crop return values.

Projected effectiveness of four of the proposed remedial measures, with respect to sediment load reduction, are given in Table 34. These projected values are based on a subjective evaluation of the information obtained through field surveys and aerial photograph interpretation (Section 5). More accurate estimates are not available but can be obtained by conducting demonstration projects in the Grand River basin.

Table 33. Major Causes of Agricultural Non-Point Source Pollution, Proposed Remedial Measures and Estimated Costs for Sub-Basins with Intensive Agricultural Development in the Grand River Basin

Sub-basins	Major Causes of Non-point Source Pollution	Remedial Measures	Estimated Costs
Middle Grand River			
1. Sub-basin GA0104	1. Stream bank erosion in Irvine Creek	1. Stream bank stabilization	$84,000
	2. Inadequate buffer strips	2. Widen buffer strips	$185,000 to $459,000 for land acquisition or $8,000/year for land rental
2. Sub-basin GA0107	1. Stream bank erosion along Cox Creek	1. Stream bank stabilization	
	2. Cattle access to Hopewell Creek	2. Fencing to restrict cattle access to streams	$1000 to $13000
	3. Flood plain cropping along Hopewell Creek	3. Discontinue cropping in the flood plain	
Canagagigue Creek			
Sub-basins GA0105 and GA0106	1. Stream bank erosion	1. Stream bank stabilization	
	2. Inadequate buffer strips	2. Widen buffer strips	
	3. Probable cattle access to streams	3. Fencing to restrict cattle access to streams	$2400 to $17600
Conestogo River			
1. Sub-basin GA0601	1. Stream bank erosion	1. Stream bank stabilization	$102,000
	2. Inadequate buffer strips	2. Widen buffers strips	$168,000 to $417,000 for land acquisition or $7,000/year for land rental
	3. Cattle access to streams	3. Fencing to restrict cattle access to streams	$2000 to $24400
2. Sub-basin GA0602	1. Stream bank erosion	1. Stream bank stabilization	$102,000
	2. Inadequate buffer strips	2. Widen buffer strips	$168,000 to $417,000 for land acquisition or $7,000/year for land rental
	3. Cattle access to stream	3. Fencing to restrict cattle access to streams	$1600 to $23600
3. Sub-basin GA0603	1. Stream bank erosion	1. Stream bank stabilization	
	2. Poor buffer strips	2. Widen buffer strips	
	3. Cattle access to stream	3. Fencing to restrict cattle access to streams	$7600 to $42200

Table 33 (Cont'd)

Nith River				
1. Sub-basin GA0201	1. Stream bank erosion	1. Stream bank stabilization	$415,000
	2. Poor buffer strips	2. Widen buffer strips	$170,000 to $422,000 for land acquisition or $4,000/year for land rental
	3. Cattle access to stream	3. Fencing to restrict cattle access to stream	$6600 to $35200
2. Sub-basin GA0202	1. Stream bank erosion	1. Stream bank stabilization	$415,000
	2. Inadequate buffer strips	2. Widen buffer strips	$170,000 to $422,000 for land acquisition or $4,000/year for land rental
	3. Flood plain cropping	3. Discontinue cropping in the flood plain	$650,000 to $1,612,000 for land acquisition or $34,000/year for land rental
3. Sub-basins GA0205, GA0206, GA0209 and GA0210	1. Stream bank erosion	1. Stream bank stabilization	$204,000
	2. Inadequate buffer strips	2. Widen buffer strips	$322,000 to $799,000 for land acquisition or $15,000/year for land rental
	3. Flood plain cropping	3. Discontinue cropping in the flood plain	$3,710,000 to $9,201,000 for land acquisition or $192,000/year for land rental

In addition to the improvement of water quality, other benefits would accrue from the implementation of the proposed remedial measures. These benefits would be mainly gained by the farmers. For example, the practice of conservation tillage on well-drained soils would result in saving of labour, time and fuel. Stream bank stabilization, restriction of cattle access to streams and the placement of buffer strips would protect stream banks as well as tile outlets, thereby reducing maintenance costs. If all these benefits are taken into account, the net costs of implementing the proposed remedial measures would be lower than those presented in Table 33.

8.3.2 Sub-basin in Development Stage

8.3.2.1 General

The undeveloped areas in the Grand River basin present a challenge to the farming communities and Government agencies to work together in order to increase the acreage of crop land and at the same time conserve the soil and ultimately the environment. All the knowledge gained on good agricultural practices can be implemented in the process of opening new land for agriculture. For example, waterways could be shaped, graded and vegetated to prevent erosion; streambanks could be protected either through the use of vegetative cover or through structural activities such as plating of the banks with stones or similar materials; buffer strips could be kept along the natural streams; minimum tillage could be encouraged on well-drained soils; etc. The end result of this joint effort will be an orderly development, increased agricultural production and a protected environment. The roles of the Government agencies and academic institutions are:

1. To evaluate the effectiveness of various remedial measures in terms of ease of application and costs of implementation. This can be effectively achieved by conducting demonstration projects in various parts of the Grand River basin.

2. To co-operate closely with the farmers in order to identify the problems and the proper solutions to these problems. The farmer should be shown that good agricultural practices are to his advantage and he should be encouraged to practise them.

8.3.2.2 Specifics

Sub-basins placed under the development stage include the upper Grand River above West Montrose dam site, the Grand River below Brantford, Eramosa River, Aberfoyle Creek, Boston Creek and Big Creek. Together, these sub-basins constitute approximately 35% of the total Grand River basin area. At present, the percentage of row crops in these sub-basins ranges from 4.4% to 20.8% of the sub-basins area. If development should proceed according to the intensive development scenarios described in Section 7.3, the projected row crop area in these sub-basins would range from 11.7% to 26.8% in the year 2001 and from 13.5% to 30/% in the year 2031. As it is indicated in Tables 22 to 26, the development would result in tremendous increases in pollutant loads if agricultural practices remain the same in the future as those in effect today. This, however, need not be the case if the joint effort described above is undertaken by the farmer and Government agencies.

Although at this time it is not possible to quantify the reduction in pollutant loads resulting from good agricultural practices in these sub-basins, it is expected that the reduction would be substantial, in the order of 50.0% to 90.0%. The projected effectiveness of four remedial meaures (streambank stabilization, fence to restrict cattle access to streams, widening of buffer strips, and no cropping in the flood plain) are given as an example in Table 34.

Table 34. Projected Effectiveness of Remedial Measures (Expressed as Percentage of Sediment Load Reduction)

	Zone	Streambank Stabilization	Fencing to Restrict Cattle Access to Streams	Widening Buffer Strips	No Cropping in Floodplain
Conestogo River U/S[1] Drayton	C1	5-30	5-10	-	-
Conestogo River D/S[2] Drayton	C2	5-30	-	5-10	N/A
Fairchild Creek	F	-	-	5-10	N/A
Irvine Creek	I	5-30	0-5	-	-
Middle Grand River	MG	5-30	0-5	0-5	N/A
Upper Nith River	N1	5-10	-	0-5	-
Upper Nith River	N2	5-30	5-10	5-10	-
Upper Nith River	N3	5-30	0-5	5-10	-
Upper Nith River	N4	5-10	0-5	5-10	10-20
Lower Nith River	N5	5-30	0-5	0-5	10-20
Lower Nith River	N6	0-5	0-5	0-5	10-20

[1]Upstream of

[2]Downstream of

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GLOSSARY

Buffer Strips (Vegetated Strips): Vegetated strips are effective along the edges of ditchbanks and other watercourses. They keep machinery away from the banks and increase the structural integrity of the channel. Such strips can act as buffers to filter sediment and pollutants from adjacent field erosion. Buffer strips can be of any practical width yet are often in the order of 10-15 feet wide to accommodate maintenance operations on ditches and streams.

Continuous Row Crops: this term relates to a cropping program where row crops are grown year-after-year in the same field without any rotation with soil-stabilizing crops such as forages or small grains.

Contour Stripcropping: identical technique to stripcropping except strips are layed out on the contour in fields with complex slopes.

Cover Crops: any crop (usually small grains) grown for a short term to provide canopy cover.

Crop Cover Management: Techniques involved in protecting the soil surface with a vegetative canopy before and after the main crop growing season. Often a winter cover crop is grown which protects the soil from erosion during fall and spring months.

Crop Residues: Crop residues are those portions of crop material (plant stalks) left in the field after harvesting. Usually residues remain rooted in the soil and often provide enough soil cover to effectively slow water run-off as well as protect much of the soil surface from the impact of rain and wind.

Crop Rotation: the inclusion of small grain and/or forage crops into an otherwise continuous row-cropping program.

Cultipack: performs much the same job as harrowing but also creates more fineness in the seedbed.

Disk-Plant: a one-pass operation with either a tandem or off-set disk followed by planting without use of any other primary or secondary tillage.

Erosion Control Structures: these are engineering practices such as grassed waterways, drop structures, diversions, etc., to control soil erosion on farm land. Control structures play an integral role with soil/crop management practices to effectively maintain soil erosion at a minimum.

Harrow: Harrowing creates an additional breakup of soil particles in final seedbed preparation. Harrows are frequently pulled in tandem behind other secondary tillage implements (e.g. disks).

Off-Set Disking: usually a primary tillage technique wherby the soil is cut, mixed and partially inverted - at a shallower depth than that of moldboard ploughing.

Parallel Terraces: This practice involves regarding slopes in sections or terraces to establish shallower slopes to slow runoff. Subsurface drainage is also employed as an integral part of terrace systems. This technique is very expensive, does not always function properly due to siltation problems and is rarely employed in Ontario. Contour diversions are much less expensive to employ and are more suitable for Ontario farm land.

PLOUGHING

Chisel Ploughing: partially incorporates surface residue and shatters the soil rather than totally inverting it as with moldboard plough. The chisel plow is a primary tillage tool.

Moldboard Ploughing: predominent primary tillage tool which inverts soil and tends to bury all surface residue.

Soil Conservation Practices: these include practical and viable techniques regarding tillage, residue management, crop cover, vegetative and structural controls on agricultural soils to keep soil erosion at a minimum while sustaining crop production.

Soil Management: the management of agricultural topsoil to sustain crop yields while maintaining good soil structure and reducing soil erosion to a minimum.

Stripcropping: the practice of growing soil-stabilizing crops (e.g. forages and small grains) in alternate parallel strips with row crops on long field slopes. The effect is to break the flow of surface water on long simple slopes.

TILLAGE

Conservation Tillage: on a given soil, any viable tillage system that is effective in maintaining good soil structure, sustaining crop yields and controlling soil erosion to a minimum.

Conventional Tillage: fall moldboard ploughing followed by spring secondary tillage (tandem disking, cultivating, harrowing); usually incorporates all surface residue and leaves a fine seedbed.

Primary Tillage: creates an initial loosening of the soil.

Reduced Tillage: Any tillage program which seeks to minimize tillage without loss in crop production.

Rotary Strip Tillage: the use of tractor-powered implements to prepare a narrow band (strip) of soil in the row area only for row-crop production.

Secondary Tillage: follows primary tillage to create a seedbed.

Zero Tillage (No till): The only soil disturbance takes place in the seed row by the planter - a one-pass system which may be considered till-plant, but only in the seed row.

Unit Area Load: Load contributed by a sub-basin divided by the area of the sub-basin.

APPENDIX 1

DESCRIPTION OF SOILS IN THE GRAND RIVER BASIN

Soils of the Grand River basin have been classified into Orders, Great Groups, Subgroups, Families, Series, Soil Types, Phases and Catenas. For the purpose of this report, however, classification of soils will be based on the types of parent materials. A brief description of major soils series in various parent material will be presented based on soil reports prepard by the Ontario Department of Agriculture and Food, Canada Department of Agriculture and the University of Guelph.

The soils of the basin may be classified into the following five major groups:

1. soils developed on glacial till;
2. soils developed on outwash sand and gravel deposits;
3. soils developed on lacustrine deposits;
4. soils developed over bedrock;
5. soils developed on miscellaneous materials.

Soils Developed on Glacial Till

Soils of this classification were formed by the weathering of calcareous till which occur at surface throughout most of the Grand River basin. A large number of soils series have developed on these glacial deposits. These soil series were established according to differences in properties such as the colour, texture and chemical composition of the soil horizons. A brief description of major soil series in this group follows:

Huron Series: These soils occupy large areas in the Dundalk till plain, the Stratford till plain and Waterloo hills physiographic units. The topography is generally gently rolling with steep slopes occurring along the sides of the larger creeks and rivers. Slopes are short and irregular. The Huron soils are moderately well drained.

The surface soil is usually loam in texture, containing 20% to 27% clay. Hence the soil is quite sticky when it is wet. In some areas especially around Arthur, Huron soils have a thin silt loam surface deposit.

Most of these soils have been cleared for farming. Hay, pasture and cereal grains are the principal crops. They are easy to cultivate except when the upper loamy horizons have eroded away leaving the clay subsoil.

Land Use limitations:

- high clay content,
- slopes may be excessively steep or complex,
- seepage often occurs on slopes.

Perth Series: These soils occur in association with the Huron soils and have the same parent materials but differ from them in having imperfect drainage. They occupy the lower slopes of hills and large portions of gently undulating ground moraine.

As a general rule the Perth soils have sufficient slope to permit some of the surface water to drain away, but much of the rainfall enters the soil. Because the underlying materials are fine textured, the movement of soil water through the soil is slow and the mottled appearance of the subsoil horizons is an indication that the moisture content is high for many months of the year.

These soils are ideal for the production of cultivated hay and cereal crops. However, for certain crops, especially alfalfa, they need artificial drainage. Tile drains are installed in some areas of Perth soils and each year more tile are being laid.

Land use limitations:

- high clay content,
- seasonally high water table,
- some slopes have complex pattern.

Guelph Series: The Guelph soils occupy the gently rolling hills and the steeply rolling drumlins in the Guelph drumlin field. These soils are also found in Waterloo hills and Horseshoe moraine (Galt and Paris moraines) physiographic units.

The Guelph soils are among the best agricultural soils in Ontario. In general, there are very few stones or boulders; the only handicap to cultivation is frequency and steepness of slopes. The soils are well drained both internally and externally but retain adequate amounts of moisture for the needs of agricultural crops. Erosion hazard is great on the steep slopes.

Dairying and livestock raising have been the major farm enterprise throughout the years. The main crops grown are pasture, hay, mixed grains, oats, winter wheat and silage corn.

Land use limitations

- slopes may be excessively steep or complex,
- moderately high erodibility.

London Series: These soils occur in association with the Guelph series. They are imperfectly drained soils on gently undulating upland areas where surface runoff is slow and internal drainge is moderate. The material from which these soils have been derived is the same as that of the Guelph series and they have the same potential for agricultural production if they are artificially drained.

The London soils are general purpose soils capable of producing arable crops or good pastures in support of mixed farming, livestock raising or dairying. The high water table delays seeding operations in the spring, may adversely affect the growth of alfalfa, or reduce the yield of winter wheat. However, when artificially drained the London soils have a higher potential than the Guelph, mainly because of their smoother topography; a factor contributing to easier management.

Land use limitations:

- seasonally high water table,
- moderately high erodibility.

Dumfries Series: The Dumfries soils have developed on stony loam till. These soils occur in the irregular moderately to steeply sloping, stony region of the Galt and Paris moraines. Since water runs rapidly off the steep slopes or readily percolates through the stony materials the Dumfries soils are well drained.

Surface erosion has occurred on most of the cultivated slopes. Indeed, the soils loss has been so great on many of the knolls that the whole profile has been removed and only the light grey parent materials remain. Erosion is light where the land has been kept under grass or tree cover. Stones and boulders are numerous both on the surface and through the soil mass. As a result, stone removal becomes an annual chore and the presence of frequent stone piles interferes with cultivation.

Most of the Dumfries soil areas have been cleared and are used for livestock raising and dairying. Because of steep slopes and stoniness somewhat less than 40% of the land is under cultivated crops. Pastures and woodlots make up the remaining 60%. Spring grains, winter wheat, mixed hay, pasture and silage corn are the main crops grown. Pastures occupy almost 35% of the Dumfries soils and are often weedy and thin.

Land use limitations:

- relatively low water-holding capacity,
- relatively low fertility,
- slopes may be excessively steep or complex,
- some areas are very stony.

Soils Developed on Outwash Sand and Gravel Deposits

Soils of this group were developed on the outwash sand and gravel deposits which were laid down near the mouths of the rivers emptying into glacial lakes and along the glacial spillways. The most important soils of this group are the Fox and Burford series.

Fox Series: Most of the sandy soils in the southern part of the Waterloo Sandhills, and in the Galt and Paris Moraines, belong to the Fox series. Before the introduction of the tobacco crop into this part of Ontario, the loamy sand and sand members of the Fox series were not used as agricultural land to any great extent, since they had poor water-holding capacity and were generally unproductive. The use of irrigation in the production of tobacco now is a common practice and in most years an adequate supply of water can be obtained for this purpose from the creeks and small streams that traverse the area.

Land use limitations:

- low water-holding capacity,
- low fertility,
- slopes may be excessively steep or complex.

Burford Series: The Burford soils are well-drained soils developed on 30 cm or less of loam or sandy loam overlying gravelly soil materials.

Soils of the Burford series occur extensively on terraces and outwash areas bordering the Grand, Speed and Conestogo rivers. There are also large areas of Burford soils on gravelly outwash and kame areas of the Elmira, Galt and Paris Moraines, and between the drumlins and fluted topography of the Guelph Drumlin Field.

The topography is gently undulating except along the edge of the terraces where slopes are often steep. Gravel, stones, and cobbles are usually present on the soil surface and throughout the soil

profile but they usually do not interfere with cultivation. Where the loam surface is thin, stones are more numerous and may interfere with cultivation especially in those areas associated with the Dumfries soils.

The Burford soils are producing crops such as spring grains, winter wheat, hay, pasture and silage corn. They are suitable for orchards and certain canning crops but are not being used for these crops to any great extent. For the most part, the agriculture on these soils is of the generalized type. Dairying is not developed intensively except in the vicinity of Geulph where there is a continuous demand for dairy products.

Land use limitations:

- low water-holding capacity,
- low fertility,
- slopes may be excessively steep or complex,
- many cobbles in places.

Soils Developed on Lacustrine Deposits

Soils of this group were developed on lacustrine deposits. The most important soils are: Waterloo, Brant, Brantford and Haldimand series.

Waterloo Series: The Waterloo series is one of the most important and wide-spread soils series in Waterloo County. It consists of well-drained soils developed on deposits of fine and very fine sandy loams. They occur mainly in the Waterloo Sandhill, but are aslo present in the Elmira, Galt, and Paris Moraines.

Most Waterloo soils in the Sandhills are associated with soils of the Brant, Fox, and St. Clements series that are developed in layered lacustrine and till deposits. The topography is irregular, steeply sloping and erosion is severe.

Most of the Waterloo sandy loam has been cleared and is used for general farming. Fair yields of cereal grains, hay and pasture can be obtained. Susceptibilty to erosion prohibits the growth of many specialized crops that might otherwise do well on this soil. Complex topography prevents the use of contour cultivation and strip cropping. Droughtiness, low fertility levels and low organic matter content also limit crop production. The soils respond to potassic, phosphatic and nitrogenous fertilization. Additions of barnyard manure are necessary to maintain and increase the organic matter content.

Land use limitations:

- slopes may be excessively steep or complex,
- relatively low water-holding capacity,
- relatively high frost-susceptibility.

Brant Series: The Brant soils have developed on well-drained lacustrine sediments of mainly loam and silt loam textures. They occupy much of the central part of the Waterloo Sandhills.

The Brant soils often grade into and are closely associated with the fine sandy loam Waterloo soils. Thin clay strata are also frequently found in the Brant soils, and may cause perched water tables and wet spots.

The Brant soils rank among the most productive agricultural soils in Waterloo County. Their main limitations for agricultural use are related to steep or complex slopes or erodibility. Brant soils with 0% to 6% single slopes have no significant limitation for use in agriculture. Corn, winter wheat, spring grains and forage crops are all grown successfully on these soils.

Land use limitations:

- slopes may be excessively steep or complex,
- high erodibility,
- slopes may have local wet or clay spots,
- high frost-susceptibility.

Brantford Series: Brantford soils have developed at well-drained locations on lacustrine deposits of silty clay loam and silty clay. They are extensively distributed throughout the Norfolk sandplain.

The parent materials of the Brantford soils consist of layered and massive deposits of lacustrine silty clay loam and silty clay. Postglacial erosion has dissected the region and produced the gently to moderately sloping topography on which the Brantford soils presently occur. A thin deposit of silt loam covers the surface of most bodies of gently sloping Brantford soils.

Brantford soils are ideally suited for the growing of many crops. They are used for growing forage crops, spring and fall grains, grain corn and canning crops. Because of the extreme erodibility of the surface silt loam, finer materials in the B and C horizons may be exposed on cultivated slopes. These clay spots tend to bake when dry and are very sticky when wet and therefore affect cultivation and uniformity of crop maturity.

Land use limitations:

- high erodibility,
- high clay content.

Haldimand Series: The Haldimand series includes the imperfectly drained, grayish clay soils which are found in the Haldimand clay plain physiographic unit.

The topography of these soils ranges from flat to very gently sloping. The grayish-brown caly parent materials are relatively impermeable to water and very sticky when wet.

The Haldimand soils have been cleared and are used mainly for the production of hay, pasture, and spring grains. Increasing use is being made of these soils for grain, corn, and canning crops. Some drainage improvement is usually necessary for best results on these soils.

Land use limitations:

- high clay content,
- poor drainage.

Soils Developed over Bedrock

Soils of this group are mainly found in the Flamborough plain physiographic unit. This small area is characterized by stony and shallow soils which developed on loam and sandy loam overlying bedrock. The Farmington series is the most widespread among these soils.

Farmington Series: The Farmington series includes well-drained, shallow soils with a depth of soil over bedrock that does not exceed 30 cm.

Most of the Farmington soils occur on level or very gently sloping areas of the Flamborough Plain where the topography is controlled by the underlying flat bedded bedrock.

Most of the Farmington soils have been cleared, but only a small acreage is presently being cultivated. Most of it is lying waste or being used for pasture. The principal problem in the utilization of these soils is the moisture deficiency that occurs almost every summer. A few farmers have overcome this problem by employing sprinkler irrigation for hgih value crops such as strawberries. Another problem is the cultivaton hazard provided by the numerous stones and outcroppings of bedrock. Some farmers have attempted to minimize tillage problems by planting forage such as birdsfoot trefoil, and using the land for permanent pasture.

Land use limitations:

- shallowness,
- low water-holding capacity.

Soils Developed on Miscellaneous Materials

This group includes soils which developed on alluvial deposits of recent origin that are found in all the channels and flood plains associated with the natural drainage network of the Grand River. It also includes organic soils (muck) which developed under very wet conditions. Their locations mark the sites of former shallow lakes, ponds, swales and stream valley bottoms. Most of the areas of muck soils are associated with the till plains, drumlin belt and moraines. Their distributions are spotty, irregular and, generally, small.

APPENDIX 2

SOIL CAPABILITY FOR AGRICULTURE

Soils in the Grand River basin have been grouped by Canada Department of Agriculture (1980) into seven classes based on soil characteristics, topography, climate and drainage. These classes are:

	Percentage of Basin Area
Class 1: Soils have no significant limitations in use for crops.	39.0%
Class 2: Soils have moderate limitations that restrict the range of crops or require moderate conservation practices.	25.5%
Class 3: Soils have moderately severe limitations that restrict the range of crops or require special conservation practices.	15.1%
Class 4: Soils have severe limitations that restrict the range of crops or require special conservation practices, or both.	4.2%
Class 5: Soils have very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible.	8.7%
Class 6: Soils are capable only of producing perennial forage crops and improvement practices are not feasible.	1.4%
Class 7: Soils have no capability for arable culture or permanent pasture.	1.0%

In general, the first three classes of soils can support sustained production of common crops if the soils are well managed. The fourth class is physically marginal for sustained arable agriculture. The fifth class can only be used for permanent pasture and hay. The sixth class can provide some sustained grazing for farm animals and the seventh class is unsuitable for agriculture.

In addition to the forementioned classification, some areas in the Grand River basin have been grouped into seven subclasses according to the conditions which may limit agricultural use. These subclasses are:

		Percentage of Basin Area
Subclass E:	Erosion damage.	less than 1.0%
Subclass I:	Flood inundation.	1.5%
Subclass P:	Stoniness.	3.1%
Subclass R:	Shallowness to solid bedrock.	1.0%
Subclass S:	Adverse soil characteristics.	31.2%
Subclass T:	Adverse topography.	17.8%
Subclass W:	Excess water other than due to overflow.	7.1%

The areas of various soil classes and subclasses in the Grand River basin are tabulated by township and county in Table 35. About 80.0% of the soils in the basin belong to Class 1, 2 or 3, with Class 1 soil being the most widespread (39.0%). Adverse soil characteristics, such as undesirable soil structure, low permeability, low natural fertility and low moisture retention capacity, are the key limiting condition, plaguing about 31.0% of the soils in the basin.

Table 35. Areal Distribution of Soils in the Grand River Basin Based on Soil Capability Classes and Subclasses.

COUNTY	TOWNSHIP	AREA OF TOWNSHIP	AREA OF TOWNSHIP WITHIN GRAND RIVER BASIN	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6
DUFFERIN	MELANCTHON	28571	19143	90706	4761	430	824	138	251
	AMARANTH	26534	18839	9426	4747	1072	177	873	206
	EAST LUTHER	15815	15815	7659	4662	1192	332	127	53
	EAST GARAFRAXA	16414	13296	5215	1338	4019	82	79	433
	COUNTY TOTAL	87334	67093	32006	15508	6713	1415	1217	943
GREY	PROTON	33132	3756	2319	223	79	27	74	40
WELLINGTON	WEST LUTHER	20453	17999	11332	2393	988	134	62	126
	ARTHUR	27228	13069	9879	1344	658	209	23	179
	WEST GARAFRAXA	20073	20073	11459	2143	3438	439	1182	166
	MARYBOROUGH	22987	20688	14975	1355	2149	1311	-	53
	PEEL	29887	29887	21360	1052	5904	382	-	38
	NICHOL	11738	11738	8306	854	1805	206	6	10
	PILKINGTON	12028	12028	7467	1716	870	117	1214	271
	GUELPH	16074	16074	8414	3577	2489	431	267	152
	ERIN	30204	18123	4168	858	5654	725	4293	764
	ERAMOSA	19148	19148	8703	2185	3839	530	1661	773
	PUSLINCH	24102	21209	1186	5527	5020	855	5308	1348
	COUNTY TOTAL	233922	200036	107249	23004	32814	5339	14016	3880
HALTON	NASSAGAWEYA	15190	5828	795	711	616	577	1340	807
	ESQUESING	28029	518	196	91	87	22	36	36
	COUNTY TOTAL	43219	6346	991	802	703	599	1376	844

Table 35 (cont'd)

COUNTY	TOWNSHIP	AREA OF TOWNSHIP	AREA OF TOWNSHIP WITHIN GRAND RIVER BASIN	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6
PERTH	WALLACE	21882	673	517	49	46	4	41	5
	MORNINGTON	21188	15722	9287	3998	670	8	1691	12
	ELLICE	23128	1813	797	733	113	2	65	4
	NORTH EASTHOPE	17226	9972	5771	615	2056	15	045	-
	SOUTH EASTHOPE	9972	1684	1116	227	249	2	79	3
	ELMA	27711	181	98	63	2	1	13	1
	COUNTY TOTAL	121107	30045	17586	5685	3136	32	2834	25
WATERLOO	WELLESLEY	28167	28167	10069	4197	7924	2125	3472	-
	WOOLWICH	21854	21854	8175	4051	1878	3460	2610	170
	WILMOT	27871	27871	9004	7119	3630	3318	4213	-
	WATERLOO	30299	30299	65978	8932	3367	1748	7750	174
	NORTH DUMFRIES	17115	17115	2189	6451	1523	2222	2497	24
	COUNTY TOTAL	125306	125306	36034	30750	18422	12873	20542	368
OXFORD	BLENHEIM	27900	27900	10042	12461	1611	451	1558	249
	BLANDFORD	10858	6734	2973	2493	659	-	433	-
	EAST ZORRA	24549	3108	2231	423	300	-	115	-
	EAST OXFORD	15955	5180	3540	454	932	-	152	-
	COUNTY TOTAL	79262	42922	18786	15831	3502	451	2258	249
WENTWORTH	BEVERLY	29462	16058	3143	2726	3686	1112	2374	1376
	ANCASTER	19539	11590	4260	2333	3672	-	29	-
	GLANFORD	9696	259	100	33	114	11	1	1
	COUNTY TOTAL	58697	27907	7503	5092	7472	1123	2404	1377

Table 35 (cont'd)

COUNTY	TOWNSHIP	AREA OF TOWNSHIP	AREA OF TOWNSHIP WITHIN GRAND RIVER BASIN	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6
BRANT	SOUTH DUMFRIES	20096	20059	5581	5204	5287	-	3567	-
	BURFORD	26605	14159	1787	7460	582	1652	1563	-
	BRANTFORD	31890	31890	8828	10490	6404	2181	3231	-
	OAKLAND	4699	4699	838	1762	757	-	755	-
	TUSCARORA	16390	16390	2082	12926	1275	-	107	-
	ONONDAGA	9399	9399	4581	755	3055	-	1008	-
	COUNTY TOTAL	109039	96596	23697	38597	17360	3833	10231	-
NORFOLK	TOWNSEND	26313	7856	520	6000	347	854	62	12
HALDIMAND	WALPOLE	29219	3281	270	2745	137	-	35	93
	SENECA	17713	6864	1252	4576	835	-	201	-
	ONEIDA	18339	16058	6260	3175	5443	-	454	726
	NORTH CAYUGA	13258	9065	2210	4036	2111	-	425	284
	SOUTH CAYUGA	6734	4403	122	3793	149	-	204	135
	DUNN	7044	6734	298	5051	395	-	793	99
	CANBOROUGH	8911	1986	-	1801	-	115	70	-
	MOULTON	14498	3497	-	1873	-	1149	424	-
	COUNTY TOTAL	115716	51888	10412	27050	9070	1264	2606	1337
BASIN TOTAL		1033047	659751	257103	168542	99618	27810	57620	9075
PERCENTAGE OF BASIN			100%	39.0%	25.5%	15.1%	4.2%	8.7%	1.4%

Appendix 3. Agricultural Land Use Inventory, 1971

SUB-BASIN	EA (1971) HA	FARM AREA HA	CROP-LAND HA	PASTURE HA	WOOD-LAND HA	WHEAT HA	OATS HA	BARLEY HA	MIXED GRAIN HA	RYE HA	TOTAL SMALL GRAIN HA	FRUIT TREES HA
GA0101	11282.	8208.	3735.	1963.	845.	9.	218.	219.	1135.	0.	1581.	0.
GA0102	52892.	39109.	21127.	9070.	2405.	237.	1053.	1447.	7308.	10.	10054.	0.
GA0103	13398.	10996.	6288.	2079.	713.	105.	196.	512.	2139.	0.	2952.	0.
GA0104	35889.	30038.	19552.	4513.	1967.	302.	549.	1597.	6119.	9.	8575.	11.
GA0105	8459.	8167.	5879.	909.	677.	74.	233.	261.	1875.	0.	2443.	26.
GA0106	1845.	1800.	1239.	299.	132.	5.	29.	57.	510.	0.	601.	2.
GA0107	29083.	24767.	17627.	2251.	2060.	420.	765.	780.	3753.	2.	5719.	29.
GA0108	4168.	2805.	1960.	263.	267.	47.	167.	43.	480.	0.	737.	8.
GA0109	2062.	1524.	1048.	109.	144.	76.	54.	129.	149.	0.	408.	1.
GA0110	1806.	1266.	988.	47.	75.	26.	46.	43.	107.	0.	223.	1.
GA0111	8119.	6921.	4254.	754.	782.	189.	266.	216.	272.	0.	943.	14.
GA0201	32156.	29182.	20611.	4507.	1703.	399.	817.	667.	8829.	1.	10712.	5.
GA0202	21657.	19192.	13379.	2236.	1845.	110.	1051.	527.	4405.	2.	6095.	10.
GA0203	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0204	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0205	10830.	9171.	6693.	896.	682.	166.	317.	225.	1619.	11.	2338.	9.
GA0206	26403.	20977.	14307.	1970.	1943.	627.	745.	562.	1776.	76.	3786.	12.
GA0207	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0208	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0209	9584.	7101.	4289.	914.	701.	273.	241.	144.	539.	120.	1317.	1.
GA0210	9539.	9888.	7032.	711.	859.	353.	460.	220.	210.	166.	1409.	19.
GA0301	3153.	1631.	597.	280.	201.	34.	35.	51.	107.	6.	233.	2.
GA0302	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0303	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0304	4717.	2645.	1116.	444.	419.	22.	62.	57.	226.	0.	367.	1.
GA0401	5704.	4044.	2171.	534.	519.	62.	76.	95.	622.	0.	854.	0.
GA0402	21534.	16972.	10160.	2383.	1688.	183.	378.	791.	2388.	0.	3740.	8.
GA0404	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0406	2571.	1731.	846.	270.	110.	22.	67.	62.	118.	0.	270.	1.
GA0407	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0408	11777.	9298.	6095.	902.	816.	184.	276.	241.	926.	200.	1827.	2.
GA0500	23980.	15358.	7357.	2483.	1927.	234.	486.	422.	1609.	0.	2750.	3.
GA0601	27253.	21771.	13104.	3854.	1461.	153.	535.	584.	5254.	39.	6565.	0.
GA0602	28826.	25139.	16081.	4709.	1899.	123.	374.	613.	6525.	0.	7635.	2.
GA0603	20902.	19409.	13970.	2377.	1437.	378.	802.	300.	5359.	3.	6841.	61.
GA0604	3507.	3327.	2462.	225.	317.	91.	166.	37.	685.	4.	973.	26.
GB0101	5447.	3447.	3303.	232.	180.	146.	163.	122.	72.	98.	601.	2.
GB0102	40748.	31852.	21284.	3031.	2714.	1205.	2933.	2056.	1421.	251.	7866.	37.
GB0103	24193.	10682.	6592.	1291.	883.	565.	961.	708.	584.	4.	2822.	29.
GB0201	12176.	9382.	6214.	461.	1002.	787.	464.	399.	115.	541.	2306.	29.
GB0202	16741.	15267.	10279.	1512.	936.	781.	1414.	934.	573.	57.	3760.	15.
GB0300	16678.	13369.	9571.	1011.	807.	530.	988.	958.	863.	3.	3342.	105.
GB0400	37614.	28873.	18234.	3292.	2246.	808.	1567.	1011.	1584.	2.	4971.	286.
GB0501	36687.	31395.	21592.	2759.	2529.	1135.	1397.	787.	3314.	960.	7592.	37.
GB0502	2596.	2434.	1793.	79.	146.	84.	96.	48.	29.	149.	405.	17.
TOTAL	625975.	499135.	322828.	65620.	40035.	10935.	20485.	17923.	73595.	2716.	125613.	813.

SUB-BASIN	GRAIN CORN HA	SILAGE CORN HA	TOTAL CORN HA	SOYBEANS HA	POTATO HA	TOBACCO HA	VEGE-TABLES HA	TOTAL ROW CROPS HA	ALFALFA HA	OTHER TAME HAY HA	TOTAL HAY HA	ANIMAL UNITS
GA0101	3.	99.	102.	0.	67.	0.	0.	169.	579.	1277.	1856.	3090.
GA0102	159.	1108.	1267.	0.	18.	0.	12.	1296.	4781.	4679.	9461.	17334.
GA0103	180.	687.	868.	0.	30.	0.	2.	900.	1584.	724.	2308.	5855.
GA0104	1935.	2868.	4804.	6.	17.	0.	9.	4837.	3591.	2193.	5784.	18306.
GA0105	425.	1259.	1684.	1.	11.	0.	4.	1701.	1275.	463.	1738.	7539.
GA0106	17.	201.	218.	2.	0.	0.	0.	220.	242.	170.	412.	1331.
GA0107	4365.	2899.	7264.	12.	17.	0.	125.	7418.	3273.	939.	4212.	15916.
GA0108	377.	177.	554.	0.	75.	0.	2.	631.	386.	192.	578.	1630.
GA0109	270.	96.	366.	0.	8.	0.	1.	375.	201.	63.	264.	729.
GA0110	388.	148.	536.	0.	2.	0.	10.	548.	157.	30.	187.	664.
GA0111	1746.	605.	2351.	6.	2.	4.	6.	2369.	725.	186.	911.	3686.
GA0201	588.	2055.	2642.	10.	0.	0.	0.	2652.	4140.	3023.	7163.	17724.
GA0202	1427.	1506.	2934.	2.	3.	5.	4.	2949.	3355.	892.	4246.	12226.
GA0203	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0204	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0205	1467.	1167.	2633.	0.	1.	21.	13.	2668.	1387.	254.	1641.	6810.
GA0206	5057.	2259.	7315.	0.	3.	146.	25.	7490.	2326.	586.	2912.	12510.
GA0207	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0208	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0209	1486.	404.	1890.	3.	1.	211.	21.	2126.	618.	209.	826.	3474.
GA0210	3637.	708.	4344.	9.	66.	249.	80.	4748.	610.	229.	840.	3852.
GA0301	50.	34.	84.	1.	0.	0.	2.	87.	217.	53.	270.	485.
GA0302	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	69.
GA0303	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	111.
GA0304	93.	114.	208.	0.	1.	0.	1.	209.	414.	108.	522.	1097.
GA0401	194.	262.	456.	1.	3.	0.	3.	463.	627.	212.	840.	1984.
GA0402	1313.	1598.	2911.	30.	38.	0.	8.	2986.	2505.	831.	3336.	9738.
GA0404	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0406	207.	76.	283.	0.	0.	0.	3.	287.	225.	50.	274.	680.
GA0407	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0408	1830.	520.	2350.	6.	159.	0.	7.	2522.	1306.	230.	1536.	4126.
GA0500	596.	704.	1300.	23.	24.	0.	4.	1352.	2375.	830.	3204.	6612.
GA0601	275.	809.	1084.	0.	0.	0.	1.	1085.	2423.	2770.	5193.	9467.
GA0602	425.	1811.	2236.	8.	1.	0.	2.	2247.	3423.	2622.	6044.	15963.
GA0603	611.	1892.	2503.	3.	32.	0.	4.	2543.	3046.	1459.	4505.	15662.
GA0604	410.	358.	769.	1.	53.	0.	4.	826.	477.	157.	634.	2680.
GB0101	1219.	136.	1355.	0.	0.	136.	32.	1524.	272.	78.	350.	1087.
GB0102	2776.	1820.	4596.	68.	123.	327.	229.	5343.	4461.	3346.	7807.	11410.
GB0103	798.	284.	1082.	40.	27.	0.	44.	1193.	1274.	1149.	2424.	3453.
GB0201	1754.	245.	1999.	11.	71.	721.	178.	2980.	609.	210.	819.	1734.
GB0202	2479.	474.	2953.	62.	7.	82.	431.	3537.	2018.	880.	2898.	4824.
GB0300	2025.	735.	2760.	46.	67.	0.	360.	3234.	1892.	694.	2587.	5419.
GB0400	5314.	1911.	7225.	39.	83.	0.	230.	7577.	3406.	1671.	5077.	12888.
GB0501	5473.	2232.	7706.	14.	89.	1441.	461.	9710.	3214.	887.	4101.	15111.
GB0502	787.	121.	909.	1.	2.	173.	58.	1143.	125.	46.	171.	559.
TOTAL	52157.	34383.	86540.	406.	1103.	3517.	2378.	93945.	63538.	34394.	97932.	258796.

SUB-BASIN	PIGS	SHEEP	HENS AND CHICKENS	CATTLE
GA0101	3227	511	2424	4117
GA0102	17332	3319	135134	22820
GA0103	7930	556	29127	7738
GA0104	35285	1306	299662	22992
GA0105	17742	41	215934	9195
GA0106	3040	6	18919	1662
GA0107	32521	679	253749	19987
GA0108	2956	14	81114	2022
GA0109	664	3	73780	916
GA0110	979	0	23842	862
GA0111	4325	300	94212	4842
GA0201	37225	152	197509	22510
GA0202	27849	280	253398	15069
GA0203	-99999	-99999	-99999	-99999
GA0204	-99999	-99999	-99999	-99999
GA0205	12849	140	104031	8721
GA0206	18732	600	152927	16438
GA0207	-99999	-99999	-99999	-99999
GA0208	-99999	-99999	-99999	-99999
GA0209	4194	161	54769	4649
GA0210	5371	310	18793	5096
GA0301	289	92	9695	650
GA0302	65	11	1141	91
GA0303	116	16	2920	145
GA0304	1107	250	20807	1410
GA0401	2437	629	36107	2442
GA0402	14147	2353	64610	12213
GA0404	-99999	-99999	-99999	-99999
GA0406	547	106	1554	923
GA0407	-99999	-99999	-99999	-99999
GA0408	4541	203	44974	5592
GA0500	9399	1681	86168	8218
GA0601	15369	328	86330	12411
GA0602	37657	256	591005	19196
GA0603	53395	279	245721	17680
GA0604	6672	58	79102	3212
GB0101	1946	173	28182	1329
GB0102	13963	1672	195380	14798
GB0103	5107	211	54530	4508
GB0201	2611	68	26619	2274
GB0202	6701	444	195379	6106
GB0300	10067	481	167357	6691
GB0400	20088	1688	374567	16128
GB0501	30759	193	315101	19046
GB0502	996	66	209	714
TOTAL	470200	19636	4636782	325413

Appendix -. Agricultural Land Use Inventory, 1976

SUB-BASIN	EA (1976) HA	FARM AREA HA	CROP-LAND HA	PASTURE HA	WOOD-LAND HA	WHEAT HA	OATS HA	BARLEY HA	MIXED GRAIN HA	RYE HA	TOTAL SMALL GRAIN HA	FRUIT TREES HA
GA0101	11282.	8418.	4732.	1475.	676.	28.	151.	438.	1319.	1.	1937.	1.
GA0102	52892.	34674.	22474.	5899.	1910.	596.	801.	2036.	6580.	7.	10020.	4.
GA0103	13398.	9262.	6327.	1003.	479.	99.	125.	459.	1858.	2.	2543.	2.
GA0104	35889.	26601.	19924.	2513.	1322.	287.	449.	1383.	4952.	11.	7082.	28.
GA0105	8459.	6253.	4882.	498.	465.	45.	88.	170.	1444.	5.	1752.	14.
GA0106	1845.	1805.	1375.	125.	105.	1.	17.	56.	524.	4.	602.	3.
GA0107	29083.	19332.	12094.	1037.	1636.	672.	426.	552.	2502.	1.	4153.	17.
GA0108	4168.	2514.	1910.	133.	193.	43.	72.	29.	384.	6.	534.	7.
GA0109	2062.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0110	1806.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0111	8119.	6223.	4119.	770.	535.	276.	212.	152.	332.	1.	973.	26.
GA0201	32156.	26520.	20880.	2442.	1382.	242.	529.	450.	6944.	11.	8176.	8.
GA0202	21657.	18075.	13748.	1262.	1582.	127.	483.	427.	3632.	19.	4688.	14.
GA0203	-99999.	693.	530.	54.	70.	8.	14.	25.	155.	0.	202.	1.
GA0204	-99999.	626.	503.	35.	43.	9.	10.	4.	102.	0.	125.	0.
GA0205	10830.	9474.	7311.	544.	675.	176.	207.	182.	1358.	3.	1926.	4.
GA0206	26403.	18194.	14793.	1339.	1345.	736.	425.	438.	1310.	29.	2938.	12.
GA0207	-99999.	442.	301.	38.	49.	26.	11.	12.	30.	0.	79.	1.
GA0208	-99999.	572.	465.	37.	35.	26.	38.	8.	22.	0.	94.	0.
GA0209	9584.	5809.	3230.	742.	407.	496.	154.	75.	376.	14.	1115.	0.
GA0210	9539.	8034.	5161.	384.	632.	449.	377.	192.	132.	45.	1196.	12.
GA0301	3153.	1292.	603.	199.	118.	45.	33.	10.	103.	0.	191.	4.
GA0302	-99999.	203.	98.	31.	21.	8.	3.	2.	19.	0.	32.	1.
GA0303	-99999.	383.	215.	49.	38.	15.	5.	7.	43.	0.	70.	1.
GA0304	4717.	2113.	988.	247.	377.	41.	18.	45.	183.	0.	287.	2.
GA0401	5704.	4430.	2745.	407.	462.	45.	153.	86.	621.	0.	905.	1.
GA0402	21534.	18302.	12896.	1492.	1581.	261.	310.	753.	2259.	0.	3583.	10.
GA0404	-99999.	225.	161.	15.	19.	5.	7.	7.	18.	0.	37.	0.
GA0406	2571.	1398.	867.	131.	101.	38.	161.	16.	116.	0.	331.	1.
GA0407	-99999.	792.	552.	72.	55.	29.	8.	10.	87.	0.	134.	0.
GA0408	11777.	6443.	4682.	395.	546.	219.	169.	180.	550.	0.	1118.	2.
GA0500	23980.	10838.	6021.	1427.	1336.	260.	420.	268.	1114.	4.	2066.	11.
GA0601	27253.	16587.	11395.	2051.	1070.	138.	362.	635.	4053.	35.	5223.	3.
GA0602	28826.	26611.	18692.	2697.	1523.	129.	385.	1027.	6283.	21.	7845.	2.
GA0603	20902.	23044.	17430.	2435.	1609.	326.	652.	373.	5596.	0.	6947.	62.
GA0604	3507.	5171.	3964.	324.	458.	99.	160.	18.	1017.	27.	1321.	27.
GB0101	5447.	3090.	2449.	114.	172.	256.	136.	67.	71.	93.	623.	4.
GB0102	40748.	33449.	24280.	2280.	2444.	2386.	2938.	1565.	1531.	368.	8788.	17.
GB0103	24193.	4645.	1083.	148.	195.	262.	40.	33.	10.	0.	345.	1.
GB0201	12176.	10587.	7845.	334.	792.	1437.	470.	286.	217.	324.	2734.	29.
GB0202	16741.	10062.	7438.	538.	621.	863.	931.	327.	418.	2.	2541.	4.
GB0300	16678.	10771.	8069.	493.	616.	776.	801.	468.	690.	25.	2760.	99.
GB0400	37614.	27874.	16670.	2099.	2114.	1011.	1273.	599.	1462.	16.	4361.	280.
GB0501	36687.	28898.	22003.	1522.	2725.	1960.	764.	411.	2793.	705.	6633.	20.
GB0502	2596.	2240.	1839.	45.	82.	323.	34.	29.	37.	157.	580.	11.
TOTAL	625975.	452969.	317744.	39875.	32616.	15274.	14822.	14310.	63247.	1936.	109590.	746.

SUB-BASIN	GRAIN CORN HA	SILAGE CORN HA	TOTAL CORN HA	SOYBEANS HA	POTATO HA	TOBACCO HA	VEGE-TABLES HA	TOTAL ROW CROPS HA	ALFALFA HA	OTHER TAME HAY HA	TOTAL HAY HA	ANIMAL UNITS
GA0101	0.	259.	259.	0.	56.	0.	1.	316.	665.	1619.	2284.	3360.
GA0102	297.	1859.	2156.	8.	7.	0.	14.	2185.	4210.	5055.	9265.	15314.
GA0103	717.	990.	1707.	0.	13.	0.	17.	1737.	1348.	632.	1980.	5514.
GA0104	2934.	3537.	6471.	3.	16.	0.	23.	6513.	3495.	1873.	5367.	17363.
GA0105	424.	1174.	1598.	0.	5.	0.	3.	1606.	1141.	381.	1634.	6409.
GA0106	52.	306.	358.	0.	0.	0.	1.	359.	304.	174.	478.	1731.
GA0107	3967.	2649.	6616.	0.	5.	0.	75.	6696.	2318.	860.	3178.	14726.
GA0108	652.	240.	892.	0.	3.	0.	6.	901.	387.	125.	513.	1835.
GA0109	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0110	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.	-99999.
GA0111	1621.	610.	2231.	7.	0.	0.	4.	2242.	723.	148.	870.	3324.
GA0201	1518.	3635.	5153.	2.	12.	0.	0.	5167.	4205.	3025.	7230.	19318.
GA0202	2544.	2075.	4619.	0.	79.	0.	37.	4735.	3356.	941.	4297.	13498.
GA0203	125.	52.	177.	0.	0.	0.	0.	177.	119.	31.	150.	516.
GA0204	144.	104.	248.	0.	0.	0.	0.	248.	97.	29.	126.	521.
GA0205	2222.	1460.	3682.	0.	1.	4.	11.	3698.	1386.	286.	1672.	7253.
GA0206	5782.	1837.	7619.	2.	4.	111.	17.	7753.	2206.	449.	2622.	10893.
GA0207	92.	58.	150.	0.	0.	0.	0.	150.	60.	11.	71.	322.
GA0208	210.	47.	257.	1.	0.	0.	2.	260.	99.	13.	112.	351.
GA0209	950.	326.	1276.	0.	2.	150.	13.	1441.	505.	157.	662.	2873.
GA0210	2418.	465.	2883.	0.	66.	206.	51.	3206.	589.	171.	733.	3160.
GA0301	75.	34.	109.	0.	0.	0.	1.	110.	181.	112.	293.	352.
GA0302	14.	7.	21.	0.	0.	0.	0.	21.	25.	18.	43.	52.
GA0303	38.	17.	55.	0.	0.	0.	0.	55.	60.	24.	85.	137.
GA0304	155.	89.	244.	0.	1.	0.	1.	246.	338.	98.	436.	1012.
GA0401	353.	422.	775.	0.	9.	0.	2.	786.	691.	340.	1031.	2317.
GA0402	3132.	2255.	5387.	10.	54.	0.	72.	5523.	2467.	985.	3452.	1962.
GA0404	54.	17.	71.	0.	0.	0.	1.	72.	42.	9.	52.	129.
GA0406	244.	79.	323.	0.	0.	0.	2.	325.	195.	97.	292.	758.
GA0407	224.	19.	243.	0.	0.	0.	1.	244.	73.	61.	134.	192.
GA0408	1583.	444.	2027.	0.	153.	0.	10.	2190.	875.	268.	1143.	3164.
GA0500	679.	599.	1278.	10.	11.	0.	11.	1310.	1809.	790.	2599.	4486.
GA0601	369.	1008.	1377.	47.	1.	0.	4.	1429.	1793.	2419.	4212.	7626.
GA0602	1428.	3212.	4640.	0.	2.	0.	1.	4643.	3721.	2842.	6765.	17938.
GA0603	1397.	3115.	4512.	0.	61.	0.	5.	4578.	3644.	2107.	5752.	21865.
GA0604	753.	738.	1491.	4.	31.	0.	5.	1531.	795.	281.	1076.	4828.
GB0101	1203.	122.	1325.	0.	1.	92.	9.	1427.	312.	69.	381.	1073.
GB0102	3696.	1635.	5331.	221.	46.	262.	384.	6244.	4234.	4638.	8872.	11351.
GB0103	413.	60.	473.	26.	1.	0.	36.	534.	43.	149.	192.	282.
GB0201	2465.	345.	2810.	17.	51.	861.	208.	3947.	802.	382.	1035.	1764.
GB0202	2095.	403.	2498.	62.	12.	61.	321.	2954.	1264.	609.	1873.	2955.
GB0300	2109.	631.	2740.	31.	31.	1.	297.	3100.	[illegible]45.	521.	2066.	4336.
GB0400	6892.	1920.	8812.	14.	58.	0.	272.	9156.	3413.	1492.	4905.	13520.
GB0501	7277.	2491.	9768.	9.	55.	1362.	506.	11780.	2680.	798.	3536.	12235.
GB0502	710.	132.	842.	0.	3.	283.	30.	1118.	110.	10.	120.	376.
TOTAL	64027.	41477.	105504.	474.	850.	3353.	2488.	112673.	58325.	35095.	93590.	242991.

SUB-BASIN	PIGS	SHEEP	HENS AND CHICKENS	CATTLE
GA0101	2170	541	1900	4592
GA0102	10726	827	96869	21443
GA0103	7859	218	27560	7362
GA0104	28602	816	204636	22572
GA0105	12509	50	115031	8172
GA0106	3556	14	17283	2209
GA0107	24659	767	200875	15494
GA0108	3922	151	95857	2160
GA0109	-99999	-99999	-99999	-99999
GA0110	-99999	-99999	-99999	-99999
GA0111	2299	167	91008	4557
GA0201	32043	109	289096	25298
GA0202	27296	326	402562	16792
GA0203	1654	0	1973	605
GA0204	1190	2	273	662
GA0205	11184	75	105887	9574
GA0206	12049	641	265020	14497
GA0207	172	81	12830	416
GA0208	626	14	38	459
GA0209	3087	119	29084	3913
GA0210	2733	95	29048	2985
GA0301	179	154	839	451
GA0302	35	8	154	72
GA0303	140	25	2506	178
GA0304	810	183	9839	1354
GA0401	2188	493	17039	3047
GA0402	11195	1486	31662	1219
GA0404	90	3	20	183
GA0406	659	156	78748	894
GA0407	87	28	150	268
GA0408	3273	266	238166	3961
GA0500	3469	587	22594	3181
GA0601	8417	203	118397	10344
GA0602	36757	227	889461	21812
GA0603	58138	219	268135	26499
GA0604	17705	126	304798	9597
GB0101	3698	4	22528	1204
GB0102	11573	800	236553	15214
GB0103	516	27	1068	360
GB0201	2787	46	75393	2603
GB0202	2373	181	13197	2730
GB0300	4359	184	117699	5823
GB0400	16375	1176	366505	17651
GB0501	19033	109	149212	16184
GB0502	1405	36	357	410
TOTAL	393597	11740	4951868	309001